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THE ECONOMIC DAMAGES OF AIR POLLUTION

WASHINGTON ENVIRONMENTAL RESEARCH CENTER

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Air pollution is a problem because it endangers man's health and the environment in which he lives. The information researched in this report indicates that the cost of air pollution damage in 1970 (for measured effects only) falls within a range of $6.1 to $18.5 billion, with a "best" estimate of $12.3 billion. A benefit-cost analytical framework for environmental decision-making is outlined. The methods that have been or can be used to estimate the damages of air pollution are identified. The strengths and weaknesses of each method are discussed. The technical coefficients method is utilized in estimating the value of air pollution damage to human health, to man-made materials, and to vegetation. A particular market study method, the property value approach, was used to estimate aesthetic and soiling-related costs. Economic losses associated with air pollution effects on domestic animals and wildlife and the natural environment are not estimated because of data limitations. Damages are allocated by major pollutant and source category. The utility and limitations of gross damage estimates are discussed, and comparison with other such estimates is made. ~~Report contains bibliography.~~ (EPA)

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THE ECONOMIC DAMAGES OF AIR POLLUTION

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ABSTRACT

Air pollution is a problem because it endangers man's health and the environment in which he lives. The information researched in this report indicates that the cost of air pollution damage in 1970 (for measured effects only) falls within a range of $6.1 to $18.5 billion, with a "best" estimate of $12.3 billion. These estimates are based on: (1) a survey of the literature on environmental economics; (2) a critical review of completed studies that have attempted to estimate air pollution damages; and (3) prevailing air quality levels in 1970. Such information on air pollution damages provides policy-makers with some understanding of the seriousness of the air pollution problem, and with some knowledge of the potential benefits of abating air pollutant emissions.

A benefit-cost analytical framework for environmental decision-making is outlined. The methods that have been or can be used to estimate the damages of air pollution are identified. These methods are: (1) technical coefficients of production and consumption; (2) market studies; (3) opinion surveys of air pollution sufferers; (4) litigation surveys: (5) political expressions of social choice; and (6) the delphi method. The strengths and weaknesses of each method are discussed.

The technical coefficients method is utilized in estimating the value of air pollution damage to human health, to man-made materials, and to vegetation. The "best" estimates of damages for these effect categories for 1970 are $4.6 billion for health, $1.7 billion (adjusted for double-counting) for materials, and $.2 billion for vegetation. A particular market study method, the site differential or property value approach, yielded a "best" damage estimate of $5.8 billion (adjusted for double-counting) for aesthetic and soiling-related costs. Economic losses associated with air pollution effects on domestic animals and wildlife and the natural environment are not estimated because of data limitations.

Estimates of damages are allocated by major pollutant and source categories. The utility and limitations of gross damage estimates are discussed, and comparison with other such estimates is made. One of the major informational gaps identified is the economic effects of automobile and related air pollutants on human health and welfare.

CONTENTS

Page

Abstract . . . .

List of Figures. . . . .

List of Tables . . . .

Acknowledgements . . . .

Sections

I Summary and Conclusions 1

II Introduction. 5
- Clean Air: A Scarce Natural Resource 5
- Why Should Government Act?. 5
- A Framework for Analysis. 8
  - What Information is Needed? 8
  - A Hypothetical Example - Decision-Making. 13
- How Can Gross Damage Estimates be Used? 19

III Methods of Assessing Air Pollution Damage 22
- Overview. 22
- Individual Methods. 23
  - Technical Coefficients of Production and Consumption 23
  - Market Studies. 25
  - Opinion Surveys of Air Pollution Sufferers. 29
  - Litigation Surveys. 32
  - Political Expressions of Social Choice. 34
  - Delphi Method 34
- What Method is Best?. 35

IV Assessment of Non-Specific Air Pollution Damages. 38
- Overview of the Problem 38
- Opinion Surveys 38
- Property Value Studies. 43
  - Ridker and Henning - St. Louis. 43
  - Zerbe - Toronto 44
  - Jaksch and Stoevener - Toledo, Oregon 45
  - Anderson and Crocker - St. Louis, Kansas City, Washington, D.C.. 45
  - Crocker - Chicago 47
  - Peckham - Philadelphia. 47
  - Spore - Pittsburgh. 48
  - Weiand - St. Louis. 48
  - Crocker - Polk County, Florida. 48
  - Flesh and Weddell - Southern California 49
  - Summary 49
- National Estimate of Aesthetic and Soiling Costs. 50

Page

V Assessment of Air Pollution Damage to Human Health . . . 56
Overview of the Problem 56
Individual Studies 58
  Ridker - Morbidity and Mortality, Respiratory Diseases 59
  Riggan - Human Health and Motor Vehicle Pollution . 61
  Jaksch - Morbidity and Air Pollution in Portland, Oregon 62
  EPA - Morbidity Selected Respiratory Diseases . . . 63
  Lave and Seskin - Mortality 64
National Estimate of Health Losses 67

VI Assessment of Air Pollution Damage to Man-Made Materials 73
Overview of the Problem 73
Individual Studies 73
  Robbins - Electrical Contacts 73
  ITT - Electrical Components 74
  Salmon - General Materials 75
  Mueller and Stickney - Rubber Products 78
  Spence and Haynie - Paints 81
  Fink - Corrosion 83
  Gillette - So_x Effects on General Materials 87
  Salvin - Dye-Fading 88
National Estimate Estimate of Materials Losses 90

VII Assessment of Air Pollution Damage to Vegetation 92
Overview of Plant Surveys 92
Individual Studies 93
  Middleton and Paulus - California, 1955 93
  Lacasse - Pennsylvania, 1969 and 1970 93
  Feliciano - New Jersey, 1971 95
  Pell - New Jersey, 1972 96
  Naegele - New England, 1971-72 96
  Millecan - California, 1970 96
  Benedict - Nationwide Survey, 1969 and 1971 97
National Estimate of Plant Damages 99

VIII Assessment of the Effects of Air Pollution on Aesthetic Properties 100
Overview of the Problem 100
Odors 101
Visibility 102
Works of Art 105
Ornamental Plantings 106
Conclusions 107

Page

IX Assessment of the Effects of Soiling 108
Overview of the Problem. 108
Individual Studies 108
Mellon Institute - Pittsburgh Nuisance 108
Beaver Report - London Smog Episode. 108
Michelson and Tourin - Household Costs 109
Ridker - Urban Soiling 111
Booz, Allen and Hamilton - Philadelphia Survey . . . 112
Conclusions. 115

X Effects of Air Pollution on Animals. 117
Overview of the Problem. 117
Domestic Animals 117
Wildlife 118
Conclusions. 119

XI Effects of Air Pollution on the Natural Environment. 120
Overview of the Problem. 120
Conclusions. 122

XII Estimation and Allocation of National Gross Damages. . . 124
Gross Damage Estimation. 124
Source Emissions 126
Assignment of Damage Costs by Pollutant and Source . . . 128

XIII Discussion 132
Some Limitations of Gross Damage Estimates 132
Comparisons Among Gross Damage Estimates 134
Some Concluding Remarks. 136
Recommendations. 139

XIV References 140
XV Bibliography of Literature on the Assessment of Air Pollution Damages. 152

FIGURES

No.		Page
1	Total Air Pollution Costs and Benefits For Hypothetical Region Z	10
2	Marginal Air Pollution Costs and Benefits For Hypothetical Region Z	14
3	Underestimation of Property Value Losses	54
4	Overestimation of Property Value Losses	54
5	Human Response to Pollutant Exposure	57

TABLES

No.		Page
1	Cost of Cleaning Up After Boiler Malfunction	41
2	Amount of Money Respondents Would Pay Annually to Reduce Air Pollution in Morgantown, West Virginia	42
3	Anderson-Crocker Property Value Regression Equations	46
4	Summary of Property Value Studies	51
5	Costs of Diseases Associated with Air Pollution	60
6	Health Cost of Air Pollution, 1963	64
7	Factors Affecting the Mortality Rate in U.S. Cities	65
8	Rough Estimates of Some Health Benefits that Can be Realized by the Control of Sulfur Dioxide, Suspended Sulfates and Suspended Particulates	68
9	Ranking of Material Economic Losses Caused by Deterioration	77
10	Estimated Costs of Air Pollution Resistant Materials	79
11	Costs of Shortened Life of Rubber Products	80
12	Interval for Exterior Repainting as a Function of Particulate Concentrations	82
13	Frequency for Exterior Wall Painting in Philadelphia as a Function of Particulate Concentration	82
14	Economic Assessment of Air Pollution Deterioration of Exterior Paints	84
15	Annual Cost of Corrosion by Air Pollution Damage of External Metal Structures, 1970	86
16	Estimated Costs of Dye Fading in Textiles	89
17	Plant Losses Due to Air Pollution	99
18	Relationship of Cleaning and Maintenance Operations to Air Particulate Levels	114

No.		Page
19	National Estimates of Air Pollution Damages (Unadjusted), 1970	125
20	Estimates of Nationwide Emissions, 1970	127
21	National Costs of Air Pollution Damage, by Pollutant and Effect, 1970	130
22	National Costs of Pollution Damage, by Source and Effect, 1970	131

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SECTION I
SUMMARY AND CONCLUSIONS

The cost of air pollution damage in the United States in 1970 is estimated to fall within the range of $6.1 billion and $18.5 billion. The "best" estimate for measured effects for that year is determined to be $12.3 billion. These estimates are based on: (1) a survey of the literature on environmental economics; (2) an extrapolation of studies that have attempted to estimate air pollution damages and that passed a critical review; and (3) prevailing air quality levels in 1970.

An evaluation is also made of the methods that can be employed to estimate the damages of air pollution. These methods are: (1) technical coefficients of production and consumption; (2) market studies; (3) opinion surveys of air pollution sufferers; (4) litigation surveys; (5) political expressions of social choice; and (6) the delphi method. It is concluded from such a review that some combination of the methods surveyed will ensure the most accurate assessment of the economic damages resulting from air pollution insults. Such damages, in turn, when properly translated, become the benefits of abating air pollutant emissions.

It is shown in this report that only the technical coefficients and market study approaches have been used with measurable success in assessing the benefits of controlling air pollution. The technical coefficients method was utilized in estimating air pollution damages to human health, man-made materials, and vegetation. The "best" (unadjusted) estimates for these effect categories for 1970 are $4.6 billion for health, $2.2 billion for materials, and $.2 billion for vegetation, and total to $7.0 billion. A market study method, the site value differential or property value approach, yielded a "best" (unadjusted) estimate of $5.9 billion. This figure represents the value in 1970 of the negative insults of air pollution that are capitalized in the residential, urban property market. It is argued in this report that capitalized in this estimate are primarily those costs associated with aesthetics and household soiling.

Since it is likely that there is some overlap in the $7.0 billion and $5.9 billion estimates, they can be considered additive only with minor adjustments. By making such adjustments, any double-counting will be minimized. With such adjustments, the $7.0 billion determined via the technical coefficients method becomes $6.5 billion and the $5.9 billion determined via the property value method becomes $5.8 billion.

The estimate of $12.3 billion for 1970 developed here, differs from the 1968 estimate of $16.1 billion developed by Barrett and Waddell because of the following reasons: (1) the 1970 estimate is based on information that wasn't available in the 1968 study; (2) the levels of air pollutants being worked with in the 1970 study are generally lower than the levels for those same pollutants in 1968; (3) a re-evaluation of the available data has forced the modification of certain assumptions in this report.

The information surveyed in this report establishes that $12.3 billion is the "best" estimate for 1970. Given the lack of conclusive information to indicate that what is estimated in the $5.9 billion does not significantly overlap with what is estimated by the $7.0 figure, the option is left for the reader to use the $7.0 billion as a measure of air pollution damages in 1970. While the evidence is far from clear, it is reasoned that as interpreted in this study, the estimates determined via the site differential and technical coefficients methods should be considered additive, with only minor adjustment for obvious areas of overlap.

While it is known that air pollution causes losses of domestic animals and wildlife, such losses were not quantified in this report because of data limitations. Air pollution is also believed to cause pervasive effects in the biosphere and on geophysical and social processes. These effects are not without some economic consequences, but until the relationships can be more clearly identified, large-system economic analysis is somewhat premature.

The cost estimates for aesthetics and soiling, health, materials, and vegetation are distributed among the several pollutants considered responsible for the effect. The pollutants considered are sulfur oxides (SO_x), particulates, and oxidants (O_x). Damages in 1970 attributable to SO_x are estimated to fall within the range \$2.8 - \$8.0 billion, with a "best" estimate of \$5.4 billion. Particulate damages are estimated to fall between \$2.7 and \$8.9 billion, with a "best" estimate of \$5.8 billion. Oxidant-related damages are estimated to fall in the range \$0.6 - \$1.6 billion, with a "best" estimate of \$1.1 billion. Every attempt is made in this attribution process to identify where data deficiencies precluded the generation of estimates. For example, health costs associated with oxidant-related air pollutants are not estimated because of the lack of data.

The same costs are distributed among sources on the basis of the relative level of pollutant emissions. Damages of \$6.1 billion in 1970 are attributed to the general source category, fuel combustion in stationary sources. Damages of \$4.0 billion are attributed to industrial process losses, \$1.1 billion to transportation, \$0.4 billion to both the agricultural burning and the miscellaneous categories and \$0.3 billion to solid waste disposal.

Although estimates are obtained and presented, the reader is cautioned concerning their use. The estimate of air pollution damages of \$12.3 billion is not to be taken as absolute, but is to be considered as indicative of the seriousness of the air pollution problem. The range of \$6.1 to \$18.5 represents the significant uncertainty in which the "best" estimate of \$12.3 billion should be couched. Limitations of gross damage estimates are spelled out in greater detail in the paper. There is certainly at least one significant limitation: many benefits to be gained from air pollution control are not yet amenable to quantification in dollars and cents. Thus, the decision framework set up in the paper is designed to take this limitation into consideration.

While these estimates provide some basic justification for environmental policies and programs, aggregate point estimate offer little policy information for setting environmental standards. The research identified in this report needs to be extended to determine more accurate dose-response relationships, i.e. damage functions, and the economic value of the receptor response over a range of pollution levels. Such information would be very useful for decision-making in matters relating to environmental management.

SECTION II
INTRODUCTION

CLEAN AIR: A SCARCE NATURAL RESOURCE

Only recently has clean air been perceived as a resource which is limited, and sometimes scarce, so that society must become involved in deciding how it is to be used. This is the fundamental argument: air pollution damages human health and welfare. But it is also true that the abatement of pollution will necessitate the use of natural, human, and capital resource--all of which may be scarce.

In other terms, air pollution results in (external) costs that must be borne by the community (i.e., increased medical and cleaning expenditures, etc.); and in the same sense, the abatement of air pollution necessitates the use of resources that could be used for other competing social goals (improved education, urban renewal, etc.). These are the two significant aspects of the environmental pollution problem. And it seems that it is here that the question of "How clean is clean enough?" is relevant. In a world where knowledge of the costs and benefits of air pollution control, implementation costs, and income redistribution or burden considerations are not known with precision, it is a very difficult task to determine environmental policy.

WHY SHOULD GOVERNMENT ACT?

The concept of "externalities" is becoming well recognized and understood. Externalities of pollution are the adverse (negative externalities) or favorable (positive externalities) effects of residuals produced by consumption, production, and distribution activities. Typically, full payment for positive externalities or full compensation for negative externalities to the party affected is not made. These compensations are not required under existing economic and legal mechanisms. Society is interested because it believes that under alternative economic and legal arrangements, positive externalities could be increased and negative externalities could be decreased until, ideally, net gains are maximized.

Air pollution represents a classic example of a negative externality. The atmosphere is a common property resource providing two services: (1) removal of waste residuals discharged by firms and individuals, and "life support" for individuals, including "support" of aesthetics and concern of individuals for future generations; and (2) "support" of material objects that individuals own. As long as there is no conflict between the two services, then there is in effect no pollution. But when the two are incompatible, negative externalities can exist.

There are many actions which are not externalities even though they possess some of the characteristics of an externality. For example, goods production and trade--positive actions--have been internalized by the market system. Traffic congestion--a negative action--has been internalized to some extent, by traffic lights and the willingness of individuals to obey them. Assigning "responsibility" or "ownership" and devising enforcement mechanisms for the purpose of achieving net gains are means of internalizing externalities. Unfortunately, comparable, "naturally evolved" institutional frameworks for internalizing air pollution costs, frequently do not exist. Such institutions do not exist because: (1) ownership of air cannot be easily defined; (2) air "congestion", for large segments of the population, has risen to the "peril" point (in a physical sense) only in recent times; and (3) only in recent times have individuals perceived air pollution as "perilous" (in both a physical and a metaphysical sence) relative to their other wants.

At first glance, one might think that traditional adaptive institutions, like the market and common law legal systems, would eventually provide a means of internalizing air pollution. But this is not likely to happen. Because the atmosphere is a common property resource and because ownership rights cannot be exclusively defined, air rights cannot, in a traditional sense, be bought and sold in a market. Moreover, costs of common law legal settlements are often prohibitive. Many individuals are affected by air pollution. This pollution often comes from a number of sources. It is extremely difficult and costly to reach agreement, within a group of affected individuals, on the extent and nature of their air pollution damages and then show in a court of law, the source of these damages.

On these bases, government regulation of air pollution is necessary and desirable. It is desirable that these regulations be designed to replicate the workings of traditional market institutions. In other words, an efficient allocation of resources will be attained when polluters act as if the costs their activities impose upon others are their own costs. A government acting to ensure efficiency should establish mechanisms such that net gains from pollution control are maximized. This government action will, ideally and as a first approximation, require standards set at a level where marginal costs of control including implementation costs equal marginal control benefits. To achieve such standards, government might provide regional planning and assign emission reductions (perhaps, for example, through the use of effluent charges) so as to minimize the costs of achieving established air quality standards in an affected region, and/or establish mechanisms for minimizing implementation costs. These are costs, for example, of setting, administering, and enforcing environmental standards.

In effect, a government operating in this fashion--setting and enforcing environmental standards so as to maximize net gains--would be internalizing air pollution externalities. Through this internalization government would be ensuring an economically efficient allocation of scarce air resources.

In a wider decision framework, however, income redistribution or burden considerations must be coupled with efficiency considerations. Who pays the cost of pollution control? Who benefits? Is the resulting income redistribution a socially "fair" one? These latter equity considerations might very well temper allocative considerations and result in smaller net efficiency gains. Political processes, in trading off efficiency gains against income redistribution or burden considerations would, in the main, determine the outcome. Nonetheless, whatever the result, it is possible in principle (as shown later) to determine the costs of various income redistribution or burden outcomes in terms of foregone efficiency gains.[1]

To sum up, the decision-maker setting environmental standards should be fully aware of all of the consequence of his actions. For various alternative enforcement schemes and for the region under study, he should be provided with comprehensive estimates of pollution control costs including direct, indirect, and implementation costs, and with comprehensive estimates of benefits and "burden" impacts. Some benefits can reasonably be measured in dollars with confidence bands; other classes of benefits can only be described in physical terms. But both costs and benefits (however quantified) and "burden" impacts should be estimated over a range of pollution control levels.

What Information is Needed?

Four lists of information--what economists call functions--are needed for presentation to environmental managers. The first list or function would display all of the appropriate costs of pollution control which would be incurred in meeting a range of pollution control levels. This list would include: (1) the direct costs of installing and operating pollution control equipment, or the extra, direct costs of undertaking process changes which result in less pollution; (2) indirect costs such as the differential costs of retraining and relocating workers when plants are retired earlier than otherwise because of the enforcement of environmental policies; and (3) costs of setting, administering, and enforcing environmental policies--so-called implementation costs.

Actually, there would be a series of these cost functions, each corresponding to a specific way of allocating emission reductions among the affected emission sources. For example, reductions could be allocated proportionately with each emission source being required to reduce its emissions by the same percentage; or, alternatively, reductions could be allocated so that for each overall level of control, specific sources incur the same cost of control on the last unit of pollution controlled. Strictly in terms of direct, indirect, and implementation costs, proportionate reduction--i.e., a 90% reduction in emissions by all polluters--is likely to be more expensive than marginally allocated reduction which treats emitters individually. The proportionate reduction approach may be chosen, however, if political considerations outweigh the extra control costs which are incurred.

In order to further clarify these concepts of tradeoffs, two cost curves or functions, C1 and C2, are illustrated in Figure 1. Control costs--including direct, indirect, and implementation costs--are measured in dollars-per-year ($/year) along the ordinate; degree of pollution control (tons/year) is measured along the abscissa. As the control level increases, empirical studies[2] have shown that the costs of control are likely to rise at an increasing rate, thus the upward bow of curves C1 and C2. Curve C1 is an example of a cost function associated with a relatively expensive way of allocating emission reductions (say, proportionate reduction) while C2 exemplifies a cost function associated with a less costly way of allocating emission reductions (say, marginally allocated reduction).

KEY:
C1 = Expensive Control Instrument
C2 = Inexpensive Control Instrument
DBU = Dollar Benefits (Upper Limits)
DB = Dollar Benefits
DBL = Dollar Benefits (Lower Limits)

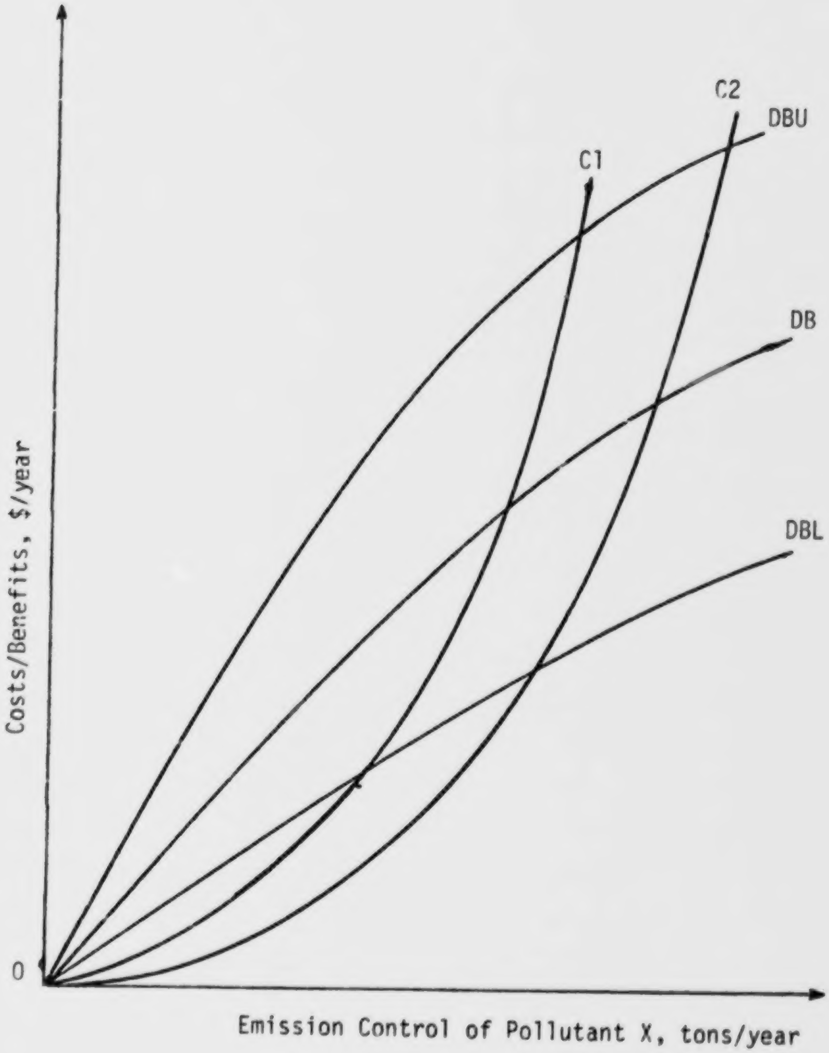

Figure 1. Total Air Pollution Costs and Benefits for Hypothetical Region Z

The second list of information or function needed for policy-making, would display, over a range of pollution control levels, those benefits resulting from pollution control which can reasonably be measured in dollars--a benefit function. Such benefits might include, for example, avoided out-of-pocket costs of soiling incurred by individuals living in a polluted environment. But these out-of-pocket costs would not cover all of the "true" costs in the soiling category. For example, individuals probably adjust to a dirty environment, in part, by undertaking extra cleaning and, in part, by relaxing their cleanliness standards. A dollar quantification of extra out-of-pocket soiling costs would probably not consider many of these "adjustment" costs. At present, there is no well-defined method of measuring in dollars, "psychic costs" resulting from a relaxation of cleanliness standards. To take another example, health benefits of pollution control could be partially quantified by measuring the health care costs which individuals would incur in a dirty environment. However, out-of-pocket costs for health care are not necessarily adequate measures of willingness to pay for such care. Therefore, given the current state-of-art, it is extremely difficult to quantify dollar benefits in some categories. Methods that have been used to quantify damages--which become benefits with effective abatement--will be reviewed in Section III.

It is useful, however, to measure those dollar benefits that can be quantified in a way which reflects the uncertainty of our benefit measures. For example, empirical studies indicate that it is extremely difficult to isolate the extra out-of-pocket health care costs associated with living in a polluted environment. Pollution is only one of a number of factors which influence health care expenditures. One solution is to use confidence bands to reflect uncertainty in benefit measures by indicating upper and lower benefit numbers within which there is, say, a 90% chance that the true benefit number lies. These confidence bands can be based upon statistical procedures, if, for example, benefit functions are quantified using statistical procedures such as regression analysis. Even in those cases where benefit measures are judgmental, benefit analysts should be asked to provide upper and lower bounds on their benefit estimates.

A dollar benefit curve or function, DB, has been drawn in Figure 1 to clarify these concepts. Curve DB represents the measured benefits in dollars over a range of control levels. It includes only benefits which can reasonbly be measured in dollars such as avoided out-of-pocket cleaning costs and avoided out-of-pocket health care costs. The function DB could be derived by estimating avoided dollar costs (i.e., dollar benefits) in a cleaner air environment where the air environment is characterized by ambient air quality and then relating these benefits to actual reductions in emissions from specific sources using an atmospheric dispersion model. In practice it may be very difficult to make this latter transformation. The curves DBL and DBU are lower and upper confidence limits on dollar benefits, respectively. They are meant to display uncertain knowledge of dollar benefits and are drawn to cover some specified range of confidence, say, for example, 90%. This range is to reflect uncertainty in dollar quantification of benefits relative to ambient air quality and uncertainty in transforming ambient air quality into specific emission reductions.

Most of our dollar benefit measurements, such as the ones reviewed in this report, have been taken in relatively dirty environments employing devices and methodologies which are tuned to these more severe conditions. Relatively less is known about dollar benefits in a cleaner environment. Hence the upper and lower hypothetical confidence limits on measured dollar benefits, DBU and DBL, have been drawn in Figure 1 with a widening spread to reflect this increased uncertainty. The bowed-over shapes of the dollar benefit functions reflect the assumption that benefits from increasing levels of pollution control, increase at a decreasing rate.

The third list of information needed for the setting of standards is a tabulation of all of the benefits from pollution control which cannot reasonably be measured in dollars. The previously mentioned psychic benefits from improved health and higher cleanliness standards, are examples. These non-dollar benefits should be fully described in physical terms over a range of control levels. Information should be provided on the numbers and characteristics of the human, plant, and animal populations and inanimate objects which are impacted by these non-dollar benefits.

The fourth list of information needed for policy-making is a description of income redistribution or burden impacts. Who are the gainers and who are the losers? Who are affected, and to what degree, by residual pollutants after standards are implemented? This information should be provided over a range of pollution control levels.

All of this cost, benefit and "burden" information should be related to specific pollutants (or groups of pollutants when effects are synergistic) and to specific regions. Weather conditions, topography, climate, the mix of emission sources, and sensitivity of the exposed population vary over time and from location to location. Furthermore, income redistribution or burden considerations may be important for particular regions and for specific sources of particular pollutants and may point to politically attractive enforcement schemes for these regions and these pollutants. In view of these temporal and spatial considerations, cost-benefit analysis can be done for different time periods on a regional basis, either for individual pollutants or mixes of pollutants. For example, in dealing with mixes of pollutants, cost savings on control systems and reduction of damage function problems are possible by solving problems of individual (but related) pollutants with a package approach.

A Hypothetical Example - Decision-Making

A hypothetical example should aid in putting into better perspective the previous discussion on what information is needed by the decision-maker. Let's now assume: (1) that a decision-maker is interested in controlling pollutant X in region Z; (2) that relevant estimates of total dollar costs, and total benefits (dollar and non-dollar), and "burden" impacts for all politically acceptable alternative enforcement schemes (say, there are only two: proportionate reduction and marginally allocated reduction) are available[3]; and (3) that this information (except for non-dollar benefits and "burden" impacts) is summarized in the cost and benefit curves drawn in Figure 1. The decision-maker has responsibility for establishing an ambient air quality level for pollutant X and would like to know the cost-benefit implications of a range of levels.

KEY:
MC1 = Marginal Control Cost (Expensive)
MC2 = Marginal Control Cost (Inexpensive)
MBU' = Marginal Benefit-Upper (Includes Dollar and Non-Dollar Benefits)
MBU = Marginal Benefit-Upper (Includes Only Dollar Benefits)
MB = Marginal Benefit Function
MBL' = Marginal Benefit-Lower (Includes Dollar and Non-Dollar Benefits)
MBL = Marginal Benefit-Lower (Includes Only Dollar Benefits)

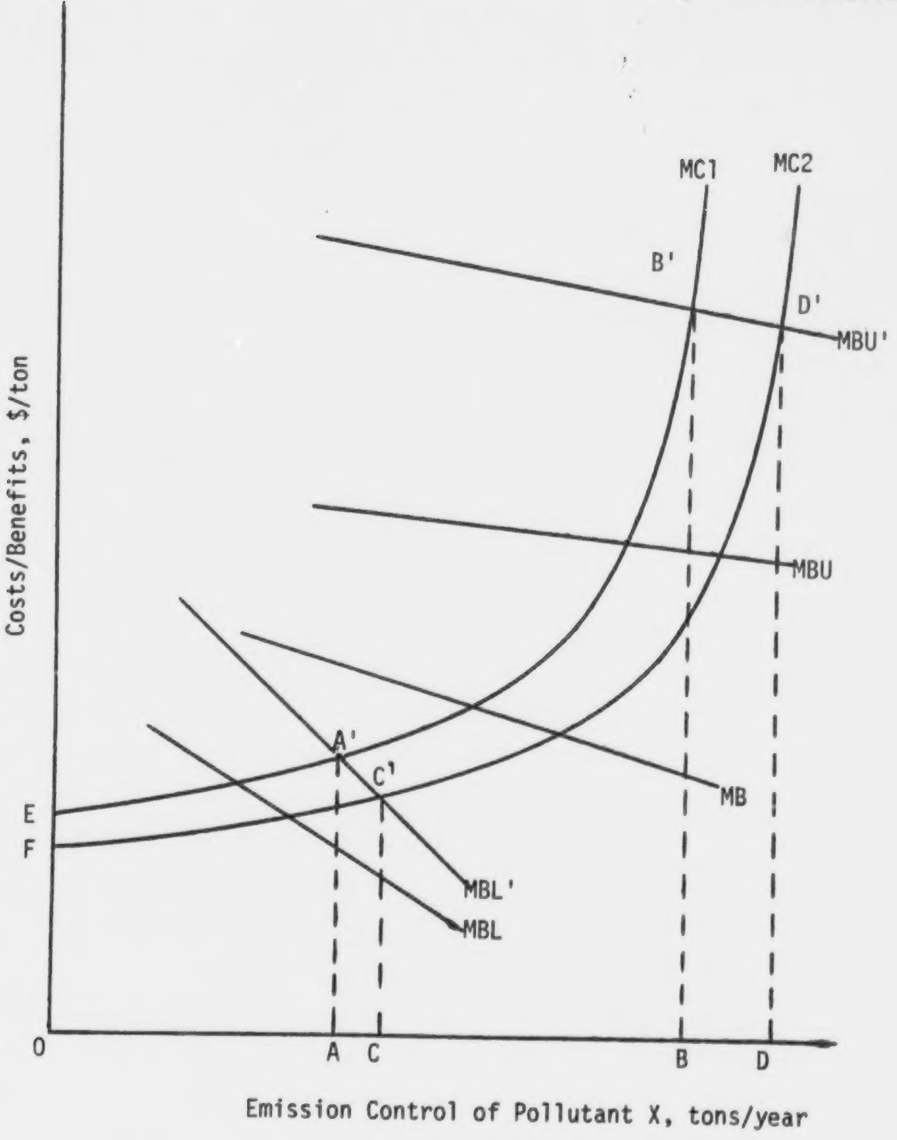

Figure 2. Marginal Air Pollution Costs and Benefits for Hypothetical Region Z

A useful way in which to present dollar cost-benefit information to the decision-maker is in the form of marginal cost and benefit curves. These are drawn in Figure 2. The units on the vertical axis are dollars per ton ($/ton); units on the horizontal axis are tons removed per year (tons/year). Curves MB, MBU, and MBL are marginal benefit, and upper and lower (confidence) marginal benefit curves--the first derivatives of curves DB, DBU, and DBL in Figure 1--respectively. MC1 is the marginal cost curve for proportionate reduction and MC2 is the marginal cost curve for marginally allocated reduction--the first derivatives of the C1 and C2 curves in Figure 1--respectively.

Implicit evaluation of non-dollar benefits must be introduced into the analysis. Let's say that after information on the character and impacts of non-dollar benefits is given to the decision-maker, he decides that these non-dollar benefits are half again as large (in dollars) as dollar benefits and that they have the same degree of uncertainty as dollar benefits. This would increase MBL and MBU at every pollutant reduction level by 50%, providing the marginal benefit schedules MBU' and MBL' respectively (see Figure 2). These marginal benefit schedules can be compared with marginal cost schedules to determine the range of control levels within which marginal costs equal marginal benefits with a confidence level of 90%, i.e., if the hypothesis is true, there is only a ten percent probability of making the mistake of rejecting it.

For example, consider MC1 in Figure 2. Marginal costs equal the lower 90% confidence level of marginal benefits at level A. At levels to the left of A, MBL' would be greater than MC1 implying that additional benefits can be gained by increasing the pollution control level. At levels to the right of A, MBL' is less than MC1 implying that net benefits are declining. Hence the best control level for maximizing net efficiency gains (i.e., total benefits minus total costs) at the lower 90% confidence level is to remove A tons of pollutant X per year. Similarly, removal level B would maximize net efficiency gains at the upper 90% confidence level. Assuming that emission source controls are implemented proportionately, this provides the control range AB within which the decision-maker can be 90% confident that net efficiency gains are maximized. Range CD is a comparable 90% confidence control range, assuming emission control is achieved by having every source incur the same marginal cost of control. As drawn in Figure 2, these hypothetical control ranges have relatively wide spreads meaning that the decision-maker can have little confidence that a specific control level within these ranges is, in fact, that level where net efficiency gains are maximized.[4]

Assume now that the decision-maker would like to set a level such that there is roughly a 90% chance that marginal benefits from pollution control will be covered by marginal costs. We can say that such a decision-maker has an aversion to risking excess pollution damage (relative to efficient damage levels) and that he is, perhaps, averse to legal challenges by environmental groups. Assume also that political realities favor proportionate control of pollution sources. Under these circumstances, the decision-maker would choose emission level B, promulgate the appropriate ambient air quality standard, and implement this standard by proportionate reduction in source emissions. Given a preference for marginally allocated reduction of pollutant X, the same decision-maker would instead, choose control level D and reap additional implicit efficiency gains of EB'D'F. But since he does not do this, income redistribution or burden considerations implied by using proportionate reduction must be at least equal to the foregone efficiency gain, EB'D'F.

Similarly, a decision-maker who has an unwillingness to risk excess pollution control costs (relative to efficient cost levels) would pick a control level near the other end of the control range. If the decision-maker wanted to set a level such that there were roughly a 90% chance that marginal costs would be covered by marginal benefits (say he was averse to legal challenges by industries having to control pollution), he would choose control level A, assuming proportionate reduction of emissions, or he would choose control level C, assuming marginally allocated reduction of emissions.

Choosing level A rather than C implies foregoing an implicit efficiency gain of EA'C'F in exchange for the income redistribution and burden "gains" implied by proportionate reduction. In other words, it is the relative price structure the decision-maker himself faces that matters.

An alternative way of presenting the information summarized in Figure 2 would be to: (1) consider, one-by-one, a number of control levels, each control level coupled with one of the two ways of reducing source emissions; and (2) characterize for each control level-source reduction pair the type of decision-maker who would choose a particular control scheme. For example, a cost-benefit analyst would describe a decision-maker, choosing control level B with proportionate reduction, in this way:

1. This decision-maker wants marginal benefits to equal or exceed marginal costs with a confidence level of 90%; he is likely to be adverse to legal challenges by environmental groups.
2. This decision-maker values non-dollar marginal benefits half again as much as dollar marginal benefits and believes that dollar and non-dollar benefits have the same degree of uncertainty.
3. This decision-maker is willing to forego an efficiency gain of EB'D'F in exchange for the income redistribution and burden "gains" implicit in proportionate reduction.

Information like this, for each control level reduction pair, could be presented to an actual decision-maker who would then have to ask himself: Which of these alternatives captures my (or my constituents') concerns and my (or my constituents') preferred tradeoffs?

So far, dynamic considerations have been glossed over in this presentation. Cost-benefit analysis should actually be carried out over some planning horizon. For a particular region and for particular pollutant sources, costs of pollution control are likely to decline over time as shifts are made from add-on control devices to process changes, and as advances in technology provide new, less costly control options. Likewise, for a particular region and for particular pollutants, pollution control benefits (i.e., avoided damages) might increase over time as population grows and as individual willingness-to-pay increases as incomes increase.

These considerations can be incorporated into cost-benefit analysis by modelling regional development and by estimating costs and dollar benefits over time and then discounting these to present values. This would provide *discounted* marginal cost and dollar benefit curves which could be analyzed exactly as the marginal curves of Figure 2 have been analyzed. Non-dollar benefits, as before, can only be described in physical terms although *implicit* values (relative to a chosen standard) can be assigned to them. Dynamic cost-benefit analysis is needed because different regional development policies will point to: different regional growth rates; different associated mixes of environmental standards and impacts; and different implementation times to meet such standards. These development tradeoffs should be made apparent to the decision maker.

This description of policy-making is not meant to be an absolute analytical framework. Events in the real world are highly uncertain; in many cases, little is known about the beneficial and harmful effects associated with pollution levels and about their "burden" impacts; it is not easy to model regional development over time. Nonetheless, cost-benefit analysis should at the very least, attempt to clearly spell out the implied and direct values which are involved in choosing alternative levels of environmental quality.

HOW CAN GROSS BENEFIT ESTIMATES BE USED?

An attempt is made in this paper to review methodologies for estimating potential air pollution control benefits and to present a systematic tabulation of existing benefit estimates for the U. S. Most of these estimates generally relate to reductions in U. S. air pollution to levels required by existing federal ambient air quality standards.

There is some danger that these estimates will be misinterpreted with respect to making precise policy decisions. To prevent this, questions about some of the numbers presented in this monograph will be posed and then answered using the preceding policy-making framework as point of reference. It is hoped that this excercise will clarify the meaning which can be attached to these benefit estimates.

Estimates for the U. S. of air pollution damages which can reasonably be measured in dollars range from a low of $6.1 billion to a high of $18.5 billion per year with a "best" estimate of $12.3 billion for 1970. Are current national primary standards too stringest if the costs, for the U. S. of meeting national primary standards, are $40 billion per year? What if, instead, the costs are only $5 billion per year?

On the basis of the information provided, it is not possible to answer these questions. Here are several reasons:

1. Only single alternative cost estimates and a single dollar benefit estimate with high and low spreads are provided in this example. Economic analysis of environmental tradeoffs requires cost and benefit functions. In other words, it is necessary to find the range of control levels at which marginal costs equal marginal benefits. Information on total costs and dollar benefits for a single control level are not adquate to judge whether or not costs and benefits are reasonably equal at the margin.

2. No information is provided here on the characteristics and the distribution of those benefits *which cannot reasonably be measured in dollars*. These non-dollar benefits--such as psychic benefits--do exist and they are likely to be quite large. Even if control costs are substantially greater than *dollar* benefits, *non-dollar* benefits could be sufficiently large *at the margin* to justify quite stringent policies.

3. No information is probided on "burden" impacts. Who pays? Who benefits? Who suffers residual damage, i.e. that damage remaining even after desired levels are achieved? This information is needed to measure the reasonableness of the "burden" tradeoffs implicit in national policies.

4. No information is provided on regional costs and benefits and regional burdens. Without this it is impossible to determine whether or not the costs exceed the benefits in any region at the nationally determined levels.

5. No information is provided on pollutant-specific costs and benefits and burdens. Without this, it is impossible to determine whether or not pollutant tradeoffs, relative to nationally determined levels for specific pollutants, are reasonable.

6. No information is provided on what is happening to regional costs and benefits and burdens and to regional development over time. Without this information, it is impossible to know whether or not nationally determined levels are dynamically efficient.

If air pollution damages in the U.S. are estimated to be $12.3 billion for 1970, what is an appropriate use of this estimate? This estimate tells us that in an aggregate sense, air pollution is a relatively serious problem and that we should probably attempt to reduce air pollution emissions. The level to which emissions should be reduced, however, can only be determined by undertaking a series of quite complicated regional cost-benefit or tradeoff analyses, each in concept like the one described previously.

There are several recent applications of gross estimates of air pollution damage to cost-benefit analyses that are worthy of mention. One is the application made in the Economics of Clean Air[5] where it is shown that the present government program of promulgating air quality standards is justified on the basis of gross damage estimates generated by Barrett and Waddell (1973). Another recent application is in the report prepared for the Office of Science and Technology, Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT)[6], in which it is concluded that present estimates of air pollution damage (again, taken from the Barrett-Waddell report) raise serious questions about the justification of the stringency of the legislated mobile source emission standards. It is quite evident that such gross damage estimates can only be used meaningfully when the user has a thorough understanding of their limitations.

In summary, gross benefit estimates will be useful to environmental managers, but only in a limited way. They will provide some measure of the seriousness of the air pollution problem. Yet such estimates will not provide the environmental manager with the kind of information that is needed to establish environmental quality standards. If the manager is to consider realistically the tradeoffs in setting such standards, information in the form of functions that relate costs to varying levels of emission control and damages to varying levels of air quality are needed. The damages-air pollution relationships--the damage functions--can be constructed using one of several methods. These methods will be discussed in the next section.

SECTION III

METHODS OF ASSESSING AIR POLLUTION DAMAGE

OVERVIEW

As discussed earlier, it is difficult to relate economic damages to varying levels of air quality. Such functions that relate economic damages to varying levels of air quality--damage functions--can be viewed as society's demand schedule for pollution abatement.[7] The demand curve for cleaner air is a schedule of what people would be willing to pay for various levels of air quality if the world, except for air pollution, were efficiently organized.

The various methods that economists use to estimate damages from air pollution have been discussed to some degree or another by Kneese,[8] Ridker,[9] Crocker,[10] Lave,[11] and Anderson and Crocker.[12] There are six general methods that have been used with different degrees of success. These methods are: (1) technical coefficients of production and consumption; (2) market studies; (3) opinion surveys of air pollution sufferers; (4) litigation surveys; (5) political expressions of social choice; and (6) the delphi method. The six methods are not necessarily mutually exclusive, but each is distinct enough to justify individual treatment in this section.

The strengths and limitations of each method, and how they have been employed are also discussed in this section. Applications of the different approaches will be discussed in detail in later sections.

INDIVIDUAL METHODS

Technical Coefficients of Production and Consumption

Copious literature exists concerning the physical and biological effects of air pollution upon artifacts and organisms. For example, there is well documented evidence that: particulates and oxides of sulfur exacerbate respiratory diseases in humans (Lave and Seskin, 1970); oxidants severely inhibit the growth rate and yield of citrus and grapes (Benedict et al., 1971); and oxides of sulfur cause excessive corrosion of metals (Fink, et al., 1971). In general, the method is developed by: (1) derivation from experimental data by the observations on objects in conditions simulating their natural environment; (2) estimation of the physical or biological damage function which relates damage to pollution levels; (3) translation of the physical damage function into economic terms; and (4) extrapolation of the function to the population, using appropriate coefficients, if an aggregate damage estimate is desired.

Because of the lack of adequate dose-response functions, a variation of the basic method outlined above is followed. In what might be termed a "damage factor approach," the investigator will estimate what proportion of a damage category can be identified as being related to or caused by air pollution. Then by applying this proportionality factor to the damage category, estimates of air pollution damage can be determined. Good examples of this damage factor approach are given in studies by Lave and Seskin (1970) and Benedict, et al. (1971). These as well as other applications of this method will be discussed in more detail in Sections V, VI, and VII.

In many cases, the magnitudes of these physical and biological damages can be predicted with some degree of accuracy because the forms of damage under restricted conditions are known. Attempts to translate these physical and biological damages into meaningful economic relationships have been less successful in identifying economic damages over a range of pollution exposures. Success in this method has been obtained only within narrowly circumscribed limits. Why? Because controlled laboratory conditions usually have little semblance to real world conditions. To minimize the confounding effects of other causal factors in the real world, the normal scientific method holds everything constant except one factor (in this case, a single pollutant or mix of pollutants). For purposes of generating damage estimates, the extrapolation of laboratory results to the true world is risky. Such a process ignores possible nonconstant marginal products, factor proportions, nonlinearities, jointness, etc.

Other problems are those of aggregation and substitution. Crocker[13] has argued that to obtain anything vaguely resembling a market estimate of collective damages, some means of making individual receptors (i.e. those who suffer damage) commensurate must be found; and then, only rarely will the aggregation process involve a straightforward arithmetic summation over all individual properties. Anderson and Crocker go on to say, "However, the collection of receptors cannot simply be treated as some arithmetic sum of individual receptors, for the prices of the substitution possibilities the single receptor views as fixed are not necessarily fixed for the collection of receptors."[14] That is, the substitution of one input by an individual will not normally affect relative prices, but if the same substitution is carried out by all receptors, then relative input prices will often be changed. The problems in employing the technical coefficients approach are those of: (1) extrapolation from controlled research environments to real world conditions; (2) aggregation of damages; and (3) enumeration of the technically feasible and then the technically efficient possibilities because of substitution.

Even given these limitations, this is the method that has been most widely used. And given the adaptability of the method of focusing on a single receptor and effect, the studies are quite amenable to the development of gross damage estimates.

Market Studies

In this approach, air pollution damages are measured through the explicit use of market valuations. The consideration, here, is the impact of air pollution dosages on human behavior as reflected in markets. This approach completely circumvents the need to know the physical or biological damage function--the basic dose-response relationship. The investigator applies statistical tools and econometric models to market data to isolate the incremental adverse effect of air pollution on a particular activity or behavior as expressed in the market place.

One particular type of market study of interest is the indirect effect of air pollution on expenditures for a particular product or activity. A good example of such a study is one by Vars and Sorenson (1972). In their study, they attempted to explain the relationship between air quality and consumer behavior, or more specifically, the consumption of recreation-related activities.

Another type of market study is the use of property values to estimate air pollution damages. One of the significant features of air pollution is its locational nature. Fortunately, then, there do exist markets in which the services and/or disservices of air pollution can be measured. As Ridker said, "If the land market were to work perfectly, the price of a plot of land would equal the sum of the present discounted stream of benefits and costs derivable from it...Since air pollution is specific to locations and the supply of locations is fixed, there is less likelihood that the negative effects of pollution can be significantly shifted onto other markets. We should, therefore, expect to find the majority of effects reflected in this market, and can measure them by observing associated changes in property values."[15]

Thus, given that people are willing to pay to avoid the effects of air pollution, property values and air pollution concentrations must vary inversely. Measures of this relationship, obtained through common multivariate estimation techniques, should yield rough estimates of the air pollution damages.[16] Good examples of this approach are given in documentation by Ridker and Henning (1967), Anderson and Crocker (1970), Peckham (1970), Crocker (1971), and Spore (1972).

The investigator will face a very significant problem in using the market study approach: he must account for all the factors that explain consumer preferences and behavior. Such an explanation is, of course, a monumental task, both theoretically and empirically.[17] And then, when robust statistical relationships have been compiled, there is the difficulty of interpreting the causality and relative importance of those pollutant measures accounted for in the study. The investigator must be sensitive to the possibilities of spurious relationships.

With respect to the causality problem, if there is a high degree of intercorrelation between two pollution measures, too much significance should not be attached to the magnitude of the coefficients of the individual pollution variables. Pollution tends to be a composite phenomenon. That is, the presence of one pollutant is frequently a reliable hint that others are also present. Thus, it is possible that the pollutants measured by these variables are not the causative agents, but are simply surrogates for others that are producing the undesirable effects.

A common criticism of the property value method is that for the method to have validity, buyers must know that pollution differs at various sites. Actually, buyers need only know that they prefer some properties to others, and other things equal, are willing to pay more for the preferred properties. If the non-preferred properties contain attributes or effects of pollution, this is sufficient for a differential property value to result. The notion of cause and effect thus rests wholly in the mind of the investigator, and not necessarily in the mind of the property buyer.[18]

Obviously, the important question arises: "What effects of air pollution are discounted and what effects are capitalized in the property market?" In other words, to what extent does the property value estimator reflect the true or complete damage cost of air pollution?

It is possible that this estimator may be biased if a good deal of air pollution injury is so insidious as to escape consumer notice. Yet public opinion surveys seem to indicate that such has not happened.[19] Ayres believes that the real estate market primarily reflects the tangible, experiential aspects of pollution: more rapid deterioration and extra cleaning and maintenance costs; the milder medical symptoms, such as shortness of breath and smarting eyes; plus, smells and dirt.[20]

Most investigators agree that costs associated with organoleptic effects (including psychic) as well as soiling-caused cleaning and maintenance expenditures are capitalized in this estimator.[21] This assumption appears consistent with the conclusion recorded by the Surgeon General's Ad Hoc Task Group on Air Pollution Research Goals which states: "The aspects of air pollution which are most apparent and of greatest personal concern to the individual probably are irritation to the eyes, nose, and throat, malodors, and the reduction of visibility. The pollutants responsible for these effects are undesirable whether or not they cause long-range health effects or economic losses, because they constitute an annoyance to people. The nuisance aspects of these effects together with those related to soiling give rise to the greatest number of complaints received by air pollution authorities. There is no doubt that a person's well-being is eventually affected by exposure to these sensory annoyances and that this may result in economic loss."[22]

Another difficulty in using this approach was voiced by Freeman: no general equilibrium model has yet been developed that is capable of predicting land or site values following some given change in air quality.[23] He argues further that "...empirical studies of land values and air pollution should await the formulation of general models from which empirically testable hypotheses can be deduced. Until such models are formulated and tested, empirical land-value studies will make little or no contribution to our knowledge of the benefits of air pollution abatement."[24] Anderson and Crocker argue that a general equilibrium model does exist in the form of an assignment model.[25] Furthermore, the model has been subjected to a test of sorts.[26]

In fact, there seems to be embodied in some work by Strotz[27] an equilibrium model acceptable to Freeman and at the same time, quite consistent with Anderson and Crocker's hypotheses. The model appears to be operational though it has not yet been fully tested. It can be termed a general equilibrium model in a pure exchange setting.[28]

Even so, Anderson and Crocker conclude that a partial equilibrium model, designed to explain the differentials in site values that exist at a given point in time, can be used to predict the change in the value of a representative site that would accompany a change in air quality, other things being equal. The implied damage cost estimate, properly interpreted as the marginal capitalized loss due to air pollution, does provide valuable information concerning the nature of air pollution damages being suffered.

Then comes the inevitable question: "What portion, then, of pollution damages are measured by the property value estimator?" Theory would state that if all consumers do not regard the two sites as perfect substitutes for each other when each site has equal air pollution dosages, then some air pollution damages will be registered in other durable assets and losses in consumers' surplus. Property value differentials, then, can be employed to obtain a lower bound on air pollution damages, and, if the sites in question have rather homogenous characteristics, their differential values represent all or nearly all damages.[29] Spore states that at a minimum, since people exposed to pollution dosages will relocate only if the pollution costs they can avoid plus the costs of moving are greater than the costs of using some alternative less-polluted site, then the costs of this adjustment (moving) will be reflected in site-value differentials.[30]

Another type of market study has been identified as the compensating income approach. That is, people who live in relatively dirty environments are, on the average, compensated by relatively higher incomes. Only little empirical work has been undertaken in this area.[31]

Opinion Surveys of Air Pollution Sufferers

In an era when Gallup and Harris polls are as commonplace as interest in the constellations, it seems quite appropriate (and popular) for those who have responsibility in making decisions about environmental management, to be concerned about public opinion. And indeed, this approach is closest to the classical economic approach in that it focuses on estimating utility and demand functions. For example, a recent opinion survey by Opatow Associates attempted to measure the public's awareness and reaction to pollution.[32] Of particular interest was the extent to which concern by the public about environmental pollution affected consumption patterns. And, the effects of pollution on consumption are what economists want to measure.

In a November 1970 popularity survey, a nationwide poll conducted by Harris showed that "pollution" ranked as the most serious problem facing many communities.[33] In a December 1971 Gallup poll, 52% of the people questioned expressed a "deep concern" about environmental pollution.[34] Such techniques have also delved into the economic aspects of the problem. In the same Gallup poll, 8% of the respondents said that they would be willing to pay $100 or more per year in added taxes "to improve our natural surroundings," and 46% said they would be willing to pay only an extra $10 or less per year.[35]

Investigators employing this method, have attempted to ascertain what people do and do not perceive as air pollution effects, distinct from whether or not they know the cause of the effects.[36] This distinction is important, for as with the property value method--contrary to the confusion on the subject--in order to determine air pollution effects, it doesn't matter whether people recognize the cause of these effects.[37] The notion of cause and effect need rest only in the mind of the investigator.

If it can be assumed that people know explicitly the effects of air pollution, then the objective is to elicit complete information from them in a way that would dissuade untruthful responses. It is well known that sample polling questions like "what would you be willing to pay to avoid (or gain) so and so," often yield misleading answers. Since every person questioned actually pays nothing to have his opinion recorded, he can respond by making extreme statements in the hope of indirectly influencing policy.

Also important in interviewing is the "free rider" aspect. Air pollution control can involve a "free rider" problem because air pollution is indivisible and pervasive in nature and moves about freely. If the respondent feels that the sum to be collected is large, he will name an arbitrarily low figure. This is the conventional problem of public goods: the interviewee reasons that even if he doesn't pay, he will be able to enjoy something others are paying for. He doesn't want to pay for abating pollution when it will benefit everyone.

Finally, there is the possibility that a respondent might not understand fully the consequences of air pollution on his health, for example. Again, in the case of health, one might be unable or unwilling to think about such consequences in purely economic terms.

In spite of many of these problems, the opinion survey approach does have its usefulness. Information on a sufferer's preception of air pollution and his attitudes toward it can be obtained by the use of questionnaire interview studies. Interviews can also provide the investigator with the sufferer's understanding of the type, nature, and extent of air pollution effects. To the extent that this knowledge is used as a basis to improve sufferer information so that he will make more complete adjustments, the air pollution damage function will be changed. Findings from studies employing the opinion survey approach are quite sketchy. These kinds of studies will be reviewed primarily in Sections IV and VIII.

Opinion surveys have shown particular usefulness in understanding: (1) how attitudes about air pollution are formed and then affected by changes in air quality; and (2) what people do and do not perceive as air pollution effects. This method can also provide some insight into what people might be willing to pay for improvement in the air environment, or perhaps, what their demand might be for the reduced risk of experiencing certain adverse effects.

Obviously, concern over the environment and individuals' ability to pay are important factors in determining willingness to pay for the abatement of air pollution. It can be shown with conventional economic theory that given one's knowledge, he purchases that much clean air to where the benefit of the last increment purchased equals the cost of abating by that last increment. By acquiring more knowledge (at a cost, of course) of the effects of air pollution, an individual's willingness to pay for different levels of air quality (i.e. pollution control) would probably change. Given the difficulty of measuring people's knowledge, it is likely that other measures will have to be used in conjunction with the interview method to determine the demand schedule for a cleaner environment.

The willingness-to-pay, if correctly determined, indicates the demand for a cleaner environment. However, it does not include the damages (say to health) that accrue to persons who cannot, or, because of low income, are unwilling to pay anything to avoid the damages. Here, the damage to an affluent person would be valued more than the same damage to a poor person.

It seems that one particular area where this method might prove very useful is in understanding the aesthetic or psychological effects of air pollution. Ridker's (1967) attempt at reaching this understanding indicates some promise. And as the general public becomes more knowledgeable about the effects of air pollution (and this can be determined through the use of the interview method), then this approach will become even more useful in understanding what people are willing to pay for varying levels of air quality.[38]

Litigation Surveys

By 1969, after many attempts at estimating pollution costs, it was sensed: that personal opinion polls often did not yield truthful responses; that surveys of the technical coefficients of household production functions failed to pick up the myraid adjustments to pollution loadings; and, that property value studies were only as good as the data used in them--and the data were often weak. It was hoped that some new technique could be developed to circumvent the difficulties of the traditional estimators. Perhaps legal cases would suggest some way of deriving information on air pollution damages from the decisions of the judicial system in adjudicating conflicts of interest over air resources.

A litigation survey project of Philadelphia cases, undertaken by Havighurst (1969) and his staff, originally had two major objectives: First, they were to locate and report in sufficient detail, all litigation--at the original or appellate levels--that might bear on the problems of finding out how much air pollution costs. Further, they were to determine the extent to which the people of Philadelphia have turned to the courts for redress. Second, using the information gathered from the study, they were to evaluate judicial data as estimators of damage functions.

The investigators spent many hours talking to lawyers, court clerks, state and local control officials and anyone who might have knowledge of past or pending litigation relevant to the search. In all, three useful cases in Philadelphia were found. Havighurst concluded that citizens of urban areas are much less inclined to attempt to control pollution through private legal action than are citizens of less polluted areas;[39] city dwellers become conditioned to air pollution. And, in a dense industrial city, there is some difficulty in knowing just what sources are primarily responsible for the pollution. Due to the paucity of interesting cases in the Philadelphia area, the project was broadened to include the Berks County-Bethlehem region. Except for a few cases which turned up, this effort, too, proved unavailing.

It was obvious that no damage functions, or even much useful data, would emerge from the records of the few cases that had been located, and therefore the most important thing to be done was to evaluate carefully the feasibility of using litigation information as a means for measuring pollution damage.

To proceed on such an appraisal required a careful comparison of the type of damage information desired by economic analysts and the type yielded by the courts. Noting that most courts, in practice, make nuisance awards on the basis of the estimated decline in the market value of the injured property and on the basis of the court's allowance for special "discomfort and annoyance," Havighurst concluded that the economic usefulness of such awards depended on the similarity between the preferences of the market and the preferences of those actually injured. In deriving estimates of economic damage, the more these preferences coincided, the stronger the case of disregarding the court's special annoyance allowance.[40]

A final product of the project was a recommendation that litigation surveys of this type be continued. Despite the lack of success in the Philadelphia area, it was felt that a national survey, perhaps of cases involving odors, would turn up enough damage awards that some tentative functions might be drawn. Havighurst suggested, however, that legal records as they now stand are frequently unsatisfactory for this purpose due to a failure to itemize pollution injuries and to specify the ambient air quality involved in the nuisance conditions.

Political Expressions of Social Choice

In utilizing this approach, one tries to gauge political expressions, representations, and exhortations in the hope that their intensity somehow corresponds to intensity of preference for one outcome over another. Yet, assessments of the outcomes of political expressions are not likely to be accurate indicators of what receptor preferences for one state of air quality relative to another would be in any real market situation. The intensities of social choice registered by political means represent only the relative valuations that occur under the constraints imposed by the political process. As such, they reflect the ability of the voter to alter the relative prices he faces.[41]

While no formal efforts have been made to specify the magnitude of the damages which usually emerge in these processes, the numerous environmental newsletters provide some appreciation for the intensities of social choices by focusing on reports where voters or taxpayers have supported (or failed to support) the passage of bond referendums, or where legislators have raised taxes to finance the construction of some pollution control activity or facility.[42]

Delphi Method

This approach, as stated by Pill, is "...a method of combining the knowledge and abilities of a diverse group of experts to the task of quantifying variables which are either intangible or shrouded in uncertainty."[43] Essentially the method is one of subjective decision-making. It is an efficient way to produce best judgments where the knowledge and opinion of experts are extracted. Desiring a particular output, those who are considered experts in the relevant area are asked to give their best solution to any given problem. This method is one that has been used by the U. S. Department of Agriculture in forecasting crop production levels. The estimate, as generated by the U. S. Department of Agriculture, of $325 million in crop losses due to air pollution, appears to have been developed in such a manner.[44] Another estimate apparently generated in such a manner is the $40 to $80 million annual cost of the adverse effects of air pollution on air travel.[45]

The Delphi method appears to be an approach that can provide quick answers in a short time frame. Yet, due to its subjective nature, many of the air pollution damages generated in this manner, have been, and probably should be largely ignored. Yet as Dalkey said, "We can either wait indefinitely until we have an adequate theory enabling us to deal with socio-metric and political problems as confidently as we do with problems in physics or chemistry, or we can make the most of an admittedly unsatisfactory situation and try to obtain the relevant intuitive insights of experts and then use their judgments as systematically as possible. The use of the Delphi approach represents an effort to proceed along the second of these alternatives."[46]

WHAT METHOD IS BEST?

Of the six methods surveyed, the technical coefficients of production and consumption, opinion surveys of air pollution sufferers, and a particular market study application, the property value method, have yielded the most promising insights into the true nature of air pollution damages. Yet even the application of these methods has been fraught with many problems. Air pollution is but one environmental stress, and there are no satisfactory methods of allocating the observed damages among a number of synergistically interacting multiple stresses, nor can the damages themselves be easily measured and reduced to economic terms.

Because of its general ease of measurement and inclusiveness, the property value, or site value differential technique, is one of the more promising approaches to the estimation of the economic losses due to air pollution. The advantage of this method is that the investigator does not have to discover and evaluate the pollution sufferers' adjustment possibilities, nor does he have to worry about how to make individual properties commensurate so that he can aggregate them. The housing market does it for him through directly observable market prices.[47] It is simply the investigator's job to correctly specify the separate influence of each characteristic, including air pollution, so that each's influence on air pollution can be discerned by well-known statistical techniques.

Two significant limitations of the property value technique which result in the underestimation of true damage costs, are: (1) the extent to which certain minimum levels of pollution are pervasive over all properties in a market, nothing could be gained by the receptor in relocating; and, (2) since there are many long-run, chronic effects that are not easily measured, it is doubtful that this technique would discern these effects. As stated earlier, concern over the limited ability of this approach to reflect even major effects, has been expressed by Ayres and Lave.

Applications of the technical coefficients approach also, can provide information on the damages of air pollution. Given that all damages will not be registered in the property value approach, the technical coefficients approach can provide insight into the fundamental processes of receptor response where air pollution has its impact. The technical coefficients and property value approaches, then, can provide complementary information. The property value approach has the advantage of ease, whereas the technical coefficients approach has the advantage of providing insight into fundamental processes.

A deeper understanding of the fundamantal adjustment processes of the receptor can also be gained by employing the interview approach. This approach can be used to determine what effects receptors perceive or fail to perceive. The information obtained can also be quite valuable for analyzing the subtle effects of air pollution. Thus, the interview approach can provide the investigator with information about receptors who suffer from air pollution effects.[48] This knowledge can be used as a basis to improve the information that sufferers have so that they will make more complete adjustments. This information, in effect, will result in some shift in the air pollution damage function.

The litigation, political expressions of social choice, and delphi approaches have been somewhat less successful in measuring the damages of air pollution than technical coefficients studies, market studies, and opinion surveys. An evaluation of the litigation approach shows that there is a theoretical problem of distinguishing between economic costs and legal costs. Also, there is the general problem that court decisions usually lack adequate dose-response information. The severe constraints and complexities of the political process afford little opportunity in determining the value of marginal changes in voters' preferences.

Given the dearth of air pollution dose-response information, it is possible that the delphi method which relies on subjective opinion rather than objective data, will be used in a more significant way. It seems obvious that where substantial information is missing, the pooled judgments of experts could provide useful information to the decision-maker on the general magnitude of damages over a range of pollution levels.

SECTION IV
ASSESSMENT OF NON-SPECIFIC AIR POLLUTION DAMAGES

OVERVIEW OF THE PROBLEM

Attempts have been made to assess the effects of air pollution on human health, materials, vegetation, aesthetics, soiling, animals and the natural environment. Studies focusing on specific effects have typically used the technical coefficients of production and consumption approach. These studies will be reviewed in later sections. It is somewhat more difficult to identify what effects are measured when the investigator undertakes market studies or opinion surveys to investigate the behaviour or awareness of air pollution sufferers.

In those cases where it is not clear what effects are being evaluated, the term "non-specific" will be used. Studies that have evaluated these non-specific damages of air pollution, will be reviewed in this Section. Such a review will afford the opportunity to assess critically the merits of each study which , in turn, will provide a basis for the extrapolation of findings to develop a national estimate of the cost of air pollution damage. This chapter will review then: (1) opinion surveys with air pollution sufferers; and (2) market studies that have employed the property value method to measure air pollution losses.

OPINION SURVEYS

Some of the earliest research to assess public awareness and concern about air pollution was done by deGroot and others (1966) in Buffalo. Their findings supported the hypothesis that there was direct relationship between the perception of the seriousness of air pollution and actual ambient air quality in the area. With respect to the perception of effects of air pollution, the study showed that: (1) the majority of people believed that air pollution is detrimental to human health; (2) three-fourths of the people queried in 1959 thought that air pollution had a bad effect on real estate; and, (3) residents perceived air pollution as bad elsewhere, but not in their own neighborhood.

Another study was performed in Clarkston, Washington, by Medalia and Finkner (1965) on the impact of odors and smoke emanating from a local pulp mill. Of approximately 100 interviews, 91% perceived air pollution in the community as an odor problem, 74% as a visibility problem, and 62% claimed it to be a problem in nose-throat irritation. Concern with air pollution was found to be unrelated to location of respondents' residence with respect to the pollution source. This absence of a relationship was probably due to the pervasive nature of the pollution. Concern with air pollution was found to vary directly with social status and with attitudes about civic pride, desire to eliminate the problem, length of residence, and occupation prestige of the household head.

A broader study by Williams and Edmisten (1965) in Nashville, Tennessee, included an examination of individual perceptions of pollution. People in 3,032 dwelling units were interviewed to test the hypothesis that perception and concern for air pollution would be directly related to neighborhood pollution levels. Their findings supported the hypothesis. Furthermore, the higher the socioeconomic status, the greater was the correlation between degree of concern and air pollution levels. They also found that the citizens' perception of air pollution was influenced more by the frequency of high daily levels of pollution than by high monthly. seasonal, or average levels.

A recent perception and attitudnal survey was reported on by Mason (1972). His research proceeded in two steps. First, a test was made of the hypothesis which stated that perceived changes in air quality in a community are defined or redefined, in part, by the local mass media and that such a definition is sufficient to form attitudes towards the topic. An empirical test of the hypothesis involved a content analysis of daily newspapers in two communities where visible changes in air quality levels were known to occur. The study took place in two cities in the Willamette Valley--Salem and Eugene, Oregon--and the pollution studied was the visibility-restricting smoke generated by the annual burning of grass stubble. Measurement of attitudes of a random sample of adults in these communities was also completed twice--once when visibility was low and once when it was normally high.

Results showed that: (1) attitudes were likely to have been formed by, and are subject to change as a result of, mass media definition; and (2) attitudes did not change as a result of known changes in air quality.

In the second step of Mason's study, a theoretical model was tested concerning the communication of air quality information to the public.[49] Interview data, gathered in the same manner as before, were analyzed by two-stage least squares. The accuracy of a respondent's perception of visibility was also determined. The results suggested that different communications models represented different stages of the same underlying communication process. Mason concluded that an understanding by public relations personnel in environmental programs of the complex communication process should enhance their efforts to speed up the formation of positive attitudes and the level of knowledge of people on the topic of environmental pollution.[50]

Once information has been gathered on people's perception and attitude concerning environmental pollution or the effects of that pollution, the next step is to value the individual's willingness to pay to reduce either the pollution or the risk of his experiencing certain effects.

Ridker[51] surveyed the residents near a steam plant to determine the cost of cleaning up after a malfunction in the boilers caused a fumigation of the neighborhood of 3,500 residential units with unusually high amounts of soot. The 1965 survey not only measured costs of cleaning, but also attempted to measure psychic costs by asking "willingness-to-pay" questions. The responses of 10 individuals who provided answers for measured and willingness-to-pay costs are shown in Table 1. Psychic costs are considered to be aesthetic costs or losses greater than the direct, measured costs that people suffer, and are valued at what these sufferers are willing to pay to avoid them.

Table 1. COST OF CLEANING UP AFTER BOILER MALFUNCTION

Respondent	Measured costs, $	Willingness-to-pay costs, $	Psychic costs, $
1	9.45	10.00	0.55
2	43.75	50.00	6.52
3	45.61	45.61	0.00
4	19.78	25.00	5.22
5	15.67	25.00	9.33
6	25.32	30.00	4.68
7	13.59	25.00	11.41
8	12.95	20.00	7.05
9	4.25	4.25	-
10	8.79	8.79	-

The results indicate that these heads of households generally were willing to pay at least the measured cost of pollution clean-up to avoid the necessity for clean-up. Usually they were willing to pay more than the measured cost. The results indicate that the residents were willing to pay, on the average, 27% above the measured cost of clean-up in order to avoid the clean-up.

These results must be qualified for several reasons: First, since the survey was constructed in only a few days, one must allow for the probability of an incomplete questionnaire and an unreliable sample. Second, the ten respondents on willingness-to-pay were too few to be representative of the psychic costs of the sample of 122 households.

Another survey on willingness-to-pay for an improvement in air quality was conducted by Lawyer (1966) among 362 of the 6,424 families in Morgantown, West Virginia. Table 2 shows the percentage of respondents by the amount each would pay each year "...if all air pollution were reduced below the point where it was noticeable (or harmful)."[52]

Table 2. AMOUNT OF MONEY RESPONDENTS WOULD PAY ANNUALLY TO REDUCE AIR POLLUTION IN MORGANTOWN, WEST VIRGINIA*

Amount, $	Respondents, %
Zero or no response	38.4
1 to 5	23.9
6 to 10	9.4
11 to 15	2.5
16 to 20	4.7
21 to 25	6.3
26 to 30	0.3
31 to 35	0.6
36 to 40	0.3
40	13.5
Total	99.9[a]

[a] Error resulted from rounding of figures

* Source: Robert E. Lawyer. An Air Pollution Public Opinion Survey for the City of Morgantown, West Virginia. West Virginia University, Morgantown. Unpublished Master's Thesis. 1966.

The average amount respondents would be willing to pay can be calculated to be $16.46. The "Zero or no response" category is not considered in the average because it is probable that many of the observations in this class are non-respondents. The average of the $1 to $5 class is taken to be $3.50 since it is assumed the class really extends to $5.00. The averages of each subsequent class are $5.00 higher than the previous one. The highest class is assumed to have an average mark of $40.

An average payment of $16.46 per year per respondent is much higher than the willingness-to-pay results of a study by Williams and Bunyard (1966).

They reported that 66% of those interviewed in a 1963 survey of the St. Louis area were willing to pay $5.00 per year in higher living costs for clean air and that 85% of those interviewed would pay $1.00 per year in higher taxes.

This brief literture survey has been a review of a rapidly growing body of knowledge concerning the perception or awareness of and the formation of attitudes about air pollution, and the willingness to pay for reductions of the perceived effects of air pollution.

PROPERTY VALUE STUDIES

Another method that has been used to measure willingness-to-pay is a particular type of market study--the property value approach (For detailed discussion of the methodology, see Section III). As with the opinion surveys reviewed earlier in this section, the property value method measures "non-specific" effects. By applying classical least-squares regression procedures, the existence of a statistically significant relationhip between air pollution and property values can be tested.

Ridker and Henning - St. Louis

The first serious use of the property value or housing market estimator was made by Ridker and Henning (1967). They used the statistical technique of multiple regression analysis to isolate the significance of air pollution--sulfation, in this case--in explaining changes in property values. Using 1960 census data and pollution readings from the 1963-64 Interstate Air Pollution Study, their regression equation explained over 90% of the variation in the median property values of the St. Louis Standard Metropolitan Statistical Area (SMSA) census tracts. The variables in their regressions were as follows:

MPV = Median property value
SUL = Annual geometric mean sulfation levels
MNR = Median number of rooms

PBR = Percentage homes recently built

HPM = Houses per mile

TIZ = Bus travel time to St. Louis central business district

HWA = Accessibility to highways

SCHI = School quality

OCR = Occupation ratio (ratio of craftsmen, foremen, operatives and laborers to total work force)

PPU = Population density

PNW = Percentage non-white residents

RILL = Dummy variable indicating whether census tract in Illinois or Missouri, orthogonal to sulfation

RMFI = Median family income, orthogonal to MNR, HPM, OCR

They concluded that the partial regression coefficients for sulfation can be interpreted as meaning that if the average sulfation levels to which any single family dwelling unit is exposed were to drop by 0.25 mg of $SO_3/100\ cm^2/day$, the value of that property can be expected to rise by at least \$83 and more likely closer to \$245. The coefficient of SUL, then, estimates the minimum sum needed to induce receptors to endure various levels of whatever pollution a sulfation index measures if all other factors have their mean values. At any inducement less than this, receptors on the average would find it to their benefit to demand either a higher payment (which in essence becomes a cost of production to the emitter to use the atmosphere for waste disposal) or a cleaner environment.

Zerbe - Toronto

Zerbe (1969) used a theoretic rationale similar to Ridker and Henning in estimating the air pollution damage to residential property in Toronto and Hamilton, Ontario, Canada. He related property values for each census tract to: four variables representing neighborhood characteristics; five variables representing property characteristics; and, two variables representing average levels of sulfur dioxide and dustfall pollution. On the basis of his best fitting equation, which explained almost 96% of the variation in median property values, Zerbe concluded that for Toronto, other things being equal, for each increase in 1 mg SO_3/day, property values will fall by an amount between \$800 and \$1800 for each single family dwelling. His best estimate was that values will fall by about \$966.[53]

Jaksch and Stoevener - Toledo, Oregon

In like manner, Jaksch and Stoevener (1970) conducted a study in Toledo, Oregon, using dustfall measurements as the pollutant variable. Their hypothesis was that air pollution represents an economic cost to the affected community and that such cost is reflected in the property values. They found that reductions in property values due to increasing air pollution levels are likely to be greater for higher-valued, more-developed properties than for less-developed, lower-valued properties. Two models were developed to analyze the relationship between dustfall pollution and residential property values, the difference being the measure of the price of residential property. In one, it was found that an increase of 1 ton/mi^2-month in dustfall caused property values to decline by $277 per acre. In the other, it was found that a similar increase in dustfall caused a decline in property values of $29 per market transaction.

Anderson and Crocker - St. Louis, Kansas City, Washington, D.C.

Anderson and Crocker (1970) gave more attention to the specification of their housing market model and to the formulation of the theoretic rationale underlying their study, and thus, significantly refined the method first employed by Ridker and Henning. Anderson and Crocker studied the covariation of sulfation, suspended particulates, and census tract median property values in St. Louis, Washington, D.C., and Kansas City. The equations most successful in explaining the variation in property values in each of the three cities are listed in Table 3.

A multiplicative (linear in logs) equation form gave the best statistical fit--highest R^2--in the regression for each city. Without exception, the signs of the coefficients for all explanatory variables, including the air pollution variables, were in agreement with a priori expectations. The hypothesis that air pollution (as Anderson and Crocker defined it) and property values are inversely related, was confirmed.

Table 3. ANDERSON-CROCKER PROPERTY VALUE REGRESSION EQUATIONS

City	Equation	$(R^2)^a$	Degrees of Freedom[b]
St. Louis	$\ln MPV = \underset{(.6332)^{c}}{3.5407} - \underset{(.0340)}{.1019} \ln (PSN) - \underset{(.0475)}{.1192} \ln (PPT) + \underset{(.0772)}{.7660} \ln (MFI)$	.7559	228
	$- \underset{(.0087)}{.0802} \ln (DLP) - \underset{(.0162)}{.0257} \ln (OLD) + \underset{(.0060)}{.0373} \ln (NWT) - \underset{(.0382)}{.1387} \ln (DIS)$		
Kansas City	$\ln MPV = \underset{(.7261)}{3.5775} - \underset{(.0396)}{.0782} \ln (PSN) - \underset{(.0362)}{.0876} \ln (PPT) + \underset{(.0898)}{.6720} \ln (MFI)$	.8231	179
	$- \underset{(.0094)}{.0405} \ln (DLP) - \underset{(.0124)}{.0721} \ln (OLD) - \underset{(.0067)}{.0058} \ln (NWT) - \underset{(.0245)}{.0623} \ln (DIS)$		
Washington, D.C.	$\ln MPV = \underset{(.4012)}{3.3901} - \underset{(.022)}{.0712} \ln (PSN) - \underset{(.0318)}{.0610} \ln (PPT) + \underset{(.0447)}{.7677} \ln (MFI)$	.6966	267
	$+ \underset{(.0059)}{.0044} \ln (DLP) - \underset{(.0103)}{.0106} \ln (OLD) + \underset{(.0064)}{.0251} \ln (NWT) - \underset{(.0158)}{.0582} \ln (DIS)$		

Where:
MPV = Median property value
PSN = Annual arithmetic mean sulfation
PPT = Annual arithmetic mean suspended particulates
MFI = Median family income
DLP = Percentage homes dilapidated
OLD = Percentage homes more than 20 years old in 1959
NWT = Percentage of homes occupied by nonwhites
DIS = Distance to central city

Notes: [a] Shows what part of the variation in property values across census tracts within the SMSA is explained by the equation.

[b] The degrees of freedom relate to the level of confidence one can have in the stability of the R^2.

[c] The figures in parentheses are the standard errors of the coefficients.

From their equations, Anderson and Crocker concluded that the pollution (sulfation and suspended particulates combined) elasticity of MPV falls between -0.1 and -0.2. Thus for every change of 0.1 mg SO_3/100 cm^2-day in sulfation plus 10 ug/m^3-day of suspended particulates over a given census tract, the best estimate of the change in that tract's MPV lies in the interval $300 to $700.

Crocker - Chicago

Crocker (1971) in an attempt to extend further and to test the methodology formulated by himself and Anderson, performed a study in Chicago. The purposes of this study were: (1) to test new economic hypotheses about the relation between property values and air pollution; and (2) to remove possible sources of statistical bias present in previous studies. In studying the covariation between air pollution dosages (sulfur dioxide and suspended particulates) and property values (using FHA and census tract data) his results were consistent with those from other property value studies.

On the average, the sum of the damage elasticities for sulfur dioxide and suspended particulates in the City of Chicago were found to be between -.30 and -.40. This would mean that the average marginal capitalized damages are about $450 for: (1) an additional 10 ug/m^3/day of suspended particulates; plus, (2) an additional part per billion by volume per day of sulfur dioxide.

Peckham - Philadelphia

Peckham (1970) studied the covariation of urban property values and air pollution to determine if the relationship determined in other studies, would hold in Philadelphia. Peckham concluded, "It does appear clear that negative and, in most cases, unambiguously significant coefficients have been found for both pollution variables, and that in confirmation of Crocker and Anderson, the elasticity of MPV with respect to both AMS (annual arithmetic mean sulfation) and SPT (annual arithmetic mean suspended particulates) is about -.2."[54] Peckham's estimates of the marginal capitalized sulfation damage of .1 mg SO_3/100 cm^2-day were (for two equations) $600 and $750.

Spore - Pittsburgh

Spore (1972) performed a cross-section analysis of the relationship between air pollution and property values in Pittsburgh. The pollutant measurements of dustfall and sulfur dioxide (as determined from sulfation data) were regressed against 1970 U.S. Bureau of the Census data. By applying classical least-squares regression procedures (multiplicative equations), the presence of a statistically significant inverse relationship between air pollution and property values was shown, confirming the conclusions of earlier studies. His analysis showed that for an average property, the effects associated with an additional 5 tons/mi^2-month of dustfall plus an additional .005 ppm/day SO_2 (or, a 10-15% increase in air pollution dosages) result in an increase in pollution damage costs of approximately $150-$200.

Weiand - St. Louis

Weiand (1970) attempted to test the hypothesis that air pollution is negatively related to property values in St. Louis. His work differed from that of Anderson and Crocker and Ridker and Henning in that he started from rather different premises. Weiand used a measure of residential acreage to derive a measure of land use intensity as the dependent variable representing the price of housing. Thus, he defined, a commodity of "housing services" as being representative of two variables, the price and the quantity of housing. He then demonstrated that housing services and property values do not vary with one another.[55] With his definition of the commodity of housing services, he studied the effect of air pollution on that variable, but found no statistically significant relationship. Anderson and Crocker argue that there is nothing logically wrong with Weiand's method, but it is fraught with more statistical problems and thus, it is much harder to identify incremental air pollution effects.[56]

Crocker - Polk County, Florida

Crocker's (1968) study in Polk County, Florida shows that the property value method is as applicable to agricultural areas as to urban areas. In fact, Crocker believes that property value estimators used in rural areas may capture a greater proportion of the damages since the health-related costs are likely to be somewhat less important.

In the Florida study Crocker investigated the economic impact of fluoride emissions that emanated from the production of phosphate fertilizers, on surrounding agricultural land. Such land was used either for the production of citrus or for the grazing of cattle. To distinguish between submarkets, separate analyses of the cattle and citrus industries were performed. The most satisfactory estimating equations for citrus was multiplicative while that for grazing lands was linear.

The explanatory variables in the citrus equation were statistically significant and possessed a sign in accordance with that expected from economic theory. Over time, the magnitude of the negative coefficient for air pollution consistently followed emission patterns, and in the years 1961 - 1962, the average reduction in sale price for citrus sites in the area was about $150 per acre. By 1964 when fluoride emissions had been significantly reduced, the differential sale prices attributable to the presence of air pollution had disappeared.[57]

Flesh and Weddell - Southern California

Flesh and Weddell (1972) studied the relationship betwen odors and property values in Southern California.[58] Using the same method as that posed by Ridker in his time-series study in St. Louis,[59] Flesh and Weddell attempted to estimate the economic costs of odors through property value differentials. The primary contention was this: if the presence of odors in an area does have negative impact on home values, the impact should manifest itself in slower growth in home prices, at least at the outset of the problem. They examined growth rates of property values in two "identical-except-for-pollution" residential neighborhoods. The study failed to show significant changes in the differential property values. Either there was no impact of odors on property values or the method of analysis and limits of the data masked the effects.

Summary

In summary, the majority of these property value studies use regression analysis to estimate a partial equilibrium, single-equation model whose explanatory variables include measures of not only air quality, but also location, neighborhood, occupant, and physical property characterstics thought to be determinants of residential property values or rents. With two exceptions,[60] the data measurements were obtained from cross-sectional samples over either individual properties or aggregates of properties, such as census tracts. And with three exceptions,[61] these studies established a statistically significant inverse relationship between air pollution and property values or rents.

Also, most studies have included attempts to uncover the presence of harmful multicollinearity and correct for its effects. Anderson and Crocker found significant collinearity for only the two pollution variables. Thus, they interpret their coefficients as a joint measure or composite of pollution. Both they and Spore agree that, based on their samples, it seems that the ability to uncover the true significance of air pollution as a determinant of property values or rents is not hindered by the presence of multicollinearlity between air pollution and other independent variable included in the regression equation.

NATIONAL ESTIMATE OF AESTHETIC AND SOILING COSTS

To estimate total damage costs using the property value technique, one would have to perform separate property value studies for residential, commercial, industrial, and agricultural land. Given the paucity of information in areas other than residential, total damage estimates in this report are only for those damages capitalized in the residential property market and measured through site and improvement differential values.

The findings of the property value studies reviewed here are summarized in Table 4. All studies agree, that air pollution is inversely related to MPV. The magnitude of the marginal capitalized sulfation damage for residential structures for a marginal decrease of 0.1 mg SO_3/100 cm^2-day, lies roughly in the range $100 to $600. This uniformity of results, for six major metropolitan areas, warrants some confidence in the worth of the housing market estimator for estimating national pollution damages.

It is well to recognize the difficulties in the way of making straightforward comparisons of the findings of different regression experiments in different cities. Ridker and Henning, as well as Zerbe use only one on the pollutant

Table 4. SUMMARY OF PROPERTY VALUE STUDIES

Study	City	Pollution Measure	Pollution Coefficient	R^2	Marginal Capitalized Damage
Ridker-Henning	St. Louis	Sulfation[a]			100[b]
Zerbe	Toronto	Sulfation[a]	-.12	.94	97[b]
	Hamilton	Sulfation[a]	-.08	.92	
Anderson-Crocker	St. Louis	Sulfation Suspended particulate	-.10 -.12*	.76	
	Kansas City	Sulfation Suspended particulate	-.08 -.09*	.82	300-700[c]
	Washington, D.C.	Sulfation Suspended particulate	-.07 -.06**	.70	
Crocker	Chicago	Sulfur dioxide Suspended particulate	.06** -.40	.77	470[d]
Peckham	Philadelphia	Sulfation Suspended particulate	-.10 -.12	.76	600-750[c]
Spore	Pittsburgh	Sulfation Dustfall	+.03* -.12	.81	150-200[e]

*Not significantly different from zero at the .01 level
**Not significantly different from zero at the .05 level

Notes:
[a] Single pollution variable probably measures effect of both sulfaction and suspended particulates
[b] Mean change in MPV per change of .1 mg SO_3/100 cm^2-day
[c] Mean change in MPV per change of .1 mg SO_3/100 cm^2-day plus 10 $\mu g/m^3$-day change in suspended particulates
[d] Mean change in MPV per change of .001 parts per million/72 hrs. SO_2 plus 10 $\mu g/m^3$-day change in suspended particulates
[e] Mean change in MPV per change of .005 parts per million/day of SO_2 plus a 5 tons/mi^2-month change in dustfall

regressors in their equations, while the others always use both. Anderson and Crocker argue that the identification of the separate influences of the two, highly correlated pollution variables, can best be achieved when both appear as regressors in the same equation. If this argument is true, it is probable that the marginal damages reported by both Ridker and Henning and Zerbe reflect the influence of both sulfation and particulate variations.[62]

Despite the pitfall that the pollutant measures in the different studies are not homogenous, it seems safe to say that in comparing the different studies, the slopes of the estimated damage functions differ from city to city. Peckham says that, "...this conclusion is no necessary discredit to the property value technique for measuring pollution damage, for cities do vary in their meteorology and emission density, and one would expect some corresponding variation in their damage functions."[63] Anderson and Crocker concluded that over the ranges of both sulfation and suspended particulates that they observed, marginal capitalized damages and the responsiveness of damages to pollution, appears to decline with increasing arithemetic mean pollutant concentrations.[64] Thus, total damages seem to increase at a decreasing rate, and the proportionate change in damages, relative to the proportionate change in pollution concentrations appears to decline with increasing arithmetic mean pollution concentrations. This pattern was observed when the results for areas within an individual city were compared, as well as comparison among cities.[65]

Given a marginal capitalized damage coefficient and assuming that sulfation changes are always evenly distributed among census tracts (i.e., a 10% drop in the annual average sulfation rate for a city implies a 10% drop in corresponding rates for each tract), crude estimates of sulfation damage (as captured in property value differentials) can be calculated by the following equation:

> DAMAGE = (Marginal capitalized sulfation damage) x (no. of marginal changes needed to reduce arithmetic annual mean sulfation rate for the metropolitan area to desired background) x (no. of housing units).

The damage given by this relation is total capitalized pollution damage, or the decrease in real property wealth caused by whatever pollution is measured by sulfation.

It should be noted that this damage equation uses linear extrapolation and consequently it can give rise to both under and overestimation biases. These biases are demonstrated in Figures 3 and 4.[66] Figure 3 is an example of underestimation, and Figure 4 is an example of overestimation. In both figures it is assumed that the slope (b) at the indicated point is at the relevant pollution coefficient taken from a property value regression and that air quality level Q* is "clean air". The solid lines are the "true" property value-pollution functions. The dashed lines are linear extrapolations of property values to coincide with "clean air" levels.

Total annual damage, or the decrease in real property income from pollution, is obtained by multiplying total capitalized damage by a discount rate reflecting the average return on capital:

TOTAL ANNUAL DAMAGE = (Discount Rate) x (DAMAGE)

Thus, the total capitalized pollution damage depends on: the choice of a marginal capitalized sulfation damage coefficient; the desired background sulfation rate; the annual arithmetic mean sulfation rate for the metropolitan area; the number of housing units over which the aggregation occurs; and, the discount rate.

In this report the following choices were made:

1. The studies reviewed here, taken together, show that the magnitude of the marginal capitalized sulfation damage for residential structures, for 0.1 mg/SO_3/100 cm^2-day, probably lies in the range of $100 to $600. For purposes of this report a range of damages will be estimated using extreme marginal capitalized sulfation damage coefficients of $200 to $500.
2. Selection of the desired background level at 0.1 mg/SO_3/100 cm^2-day was guided by the annual sulfation averages in selected suburban and rural regions.[67]
3. Annual arithemetic mean sulfation rates were established for all metropolitan areas either by: (a) using sulfation data on annual arithmetic means from the Interstate Surveillance Project;[68]

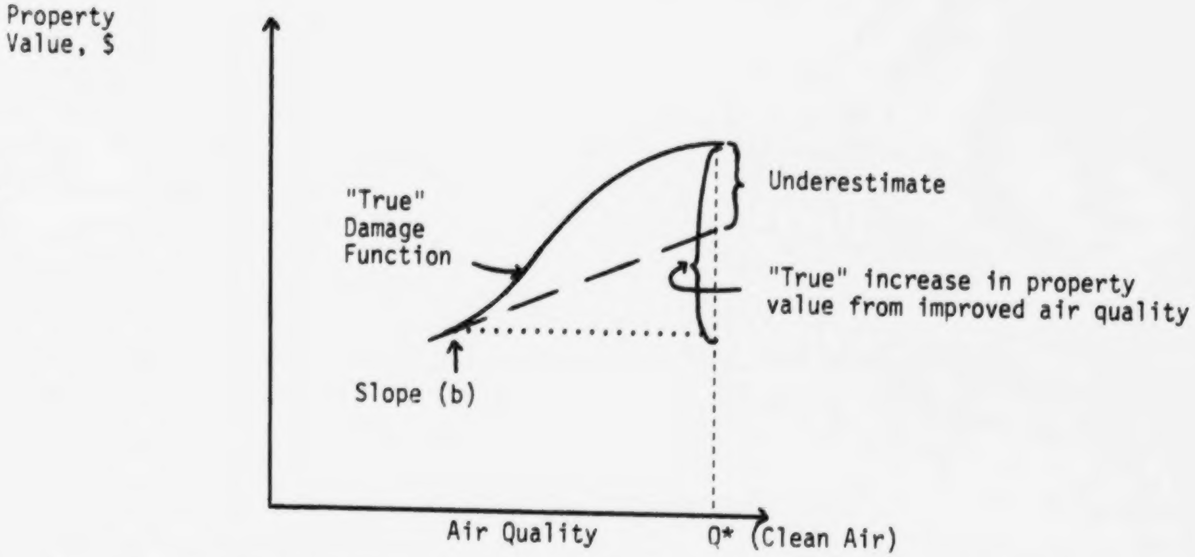
Property Value, $
"True" Damage Function
Underestimate
"True" increase in property value from improved air quality
Slope (b)
Air Quality
Q* (Clean Air)

Figure 3. Underestimation of Property Value Losses

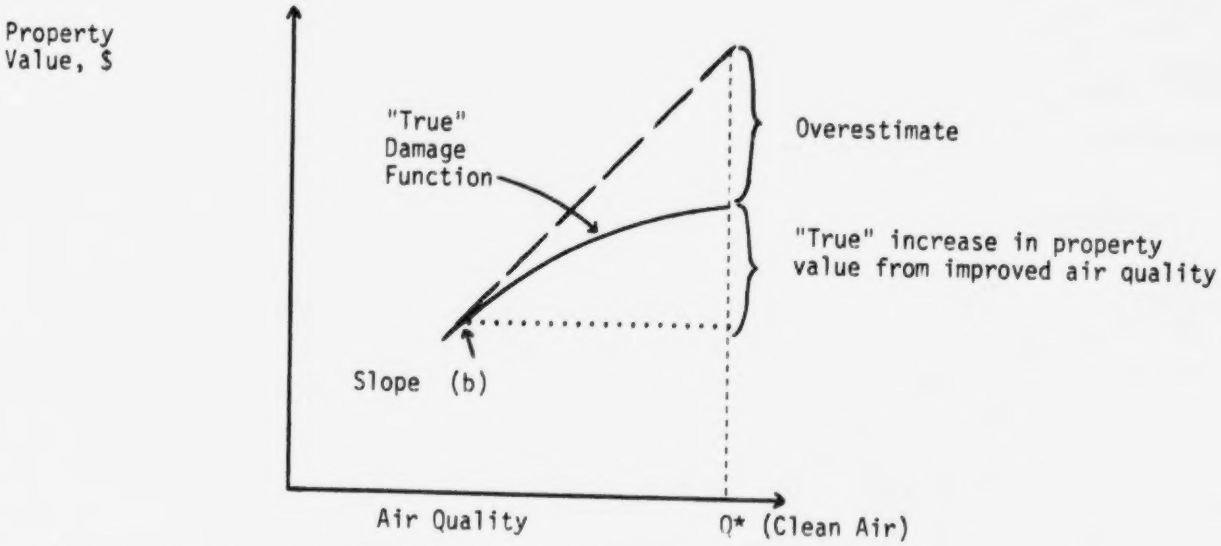
Property Value, $
"True" Damage Function
Overestimate
"True" increase in property value from improved air quality
Slope (b)
Air Quality
Q* (Clean Air)

Figure 4. Overestimation of Property Value Losses

(b) using available sulfation data from EPA's SAROAD data bank and averaging monthly data; or (c) estimation for those metropolitan areas for which sulfation data were lacking, based on a regression of annual sulfur oxides (SO_x) emission data on sulfation annual averages.

4. All estimates were calculated for the number of year-round housing units in each metropolitan area as given for 1970.[69]

5. As an approximation to an average return on all real property wealth in the economy, a 10% discount rate was uniformly used in all calculations.

As a result of the calculations described above, and assuming a range of marginal capitalized damage coefficients of \$200 to \$500 for each reduction in 0.1 mg/SO_3/100 cm^2-day, the national annual estimate for 1970 of air pollution damages measured via the property value differential method comes to \$3.4 to \$8.4 billion. A best approximation would probably be a middle estimate for a MPV of \$350, or a total damage of \$5.9 billion.

In conclusion, this estimate: (1) spans all housing units within all metropolitan areas; (2) assumes that pollution changes are spread evenly over all census tracts; (3) assumes that there is a negative relationship between sulfation and MPV; and (4) indicates the approximate amount that residents of American cities would demand, under emitter liability, to forego asserting their rights to have pollution abated so that arithmetic mean sulfation rates in all SMSA's would be 0.1 mg/SO_3/100 cm^2-day or lower.

As argued earlier (see Section III), it is believed that the costs associated with aesthetic effects as well as soiling-caused cleaning and maintenance expenditures are capitalized in this estimator. These costs reflect the tangible, experiential "disamenities" associated with air pollution. Here, the \$5.9 billion is used as an estimate of the damages to aesthetic properties and soiling, although it is recognized that other effects may be included in this estimate.

SECTION V
ASSESSMENT OF AIR POLLUTION DAMAGE TO HUMAN HEALTH

OVERVIEW OF THE PROBLEM

It is common to see references that cite health effects separate from the economic effects of air pollution. One inference can be drawn from this division: the effects of air pollution on health transcend economic values. While in fact there is a value, it is not easily measured. The separation may have been influenced largely by the absence of cost estimates for health relative to other types of damages.

What we are interested in here is how air pollution affects: illness and death rates, including partial disability; absence from work and school; and general expenditures on health protection and care. For example, we would like to know how many days of good health or work would be gained by a specific reduction in pollution. The obvious difficulty is: isolating the subtle, marginal effect of pollution on the complex human organism.

If health is defined as the general state of well-being, it might be convenient to think of a five-stage human response spectrum of increasing severity at a given level of air pollution (see Figure 5). While a significant percent of a population might be exposed to air pollution, only a smaller portion will be adversely affected, and then still a smaller fraction affected to the degree of death. The dashed line through the middle of the response spectrum in Figure 5 indicates that below this line, the health response is probably not economically significant. Above this dashed line, the response is expected to be of economic significance.

As indicated by the dotted line in Figure 5, the distinction between "psychic" and "normal" morbidity costs is unclear. While it is believed that such psychic costs do exist, they are probably only partially measured by "normal" morbidity indicators such as work-loss days, doctor visits, etc. Thus, any quantification of health costs that considers only morbidity and mortality costs will underestimate total health costs. While recognizing that these

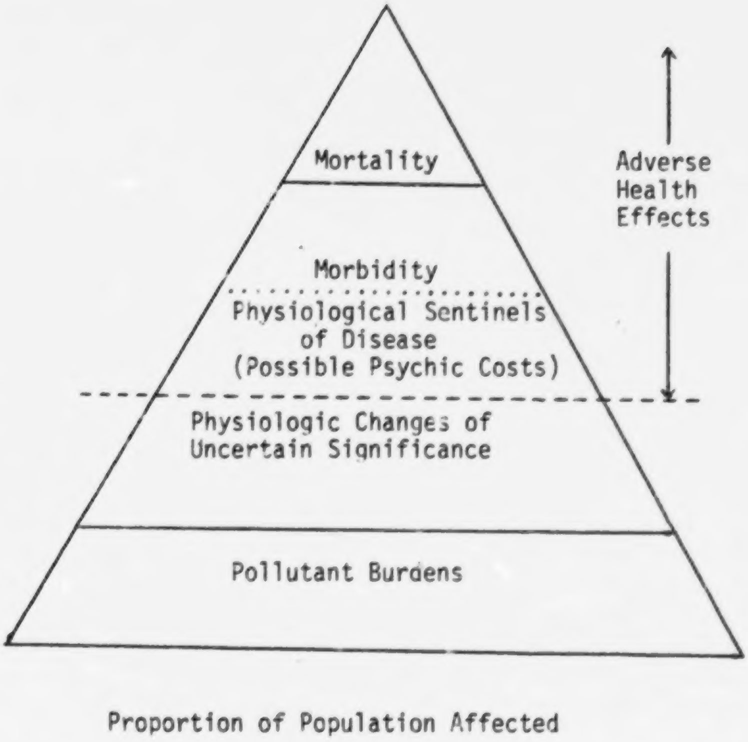
Mortality
Morbidity
Physiological Sentinels of Disease (Possible Psychic Costs)
Physiologic Changes of Uncertain Significance
Pollutant Burdens
Adverse Health Effects
Proportion of Population Affected

Figure 5. Human Response to Pollutant Exposure[a]

[a] Adapted from: C.M. Shy and J.F. Finklea, Air Pollution Affects Community Health. Environ. Sci. and Technol. 17 (3):205, March 1973.

subtle psychic costs are important, because of data limitations in this area, the analysis here will be restricted to the areas of morbidity and mortality.

Investigations focusing on the impact of air pollution on mortality rates, and on morbidity rates, represent two distinct areas of research. Death is often the result of a large number of unrelated causes. For example, a general "urban factor" has been identified as a causal agent in explaining mortality rates.[70] People in cities tend to lead more tense and less healthy lives; they smoke more, tend to be more overweight, and get less exercise. Somehow, the effects of air pollution must be separated from other causes explaining this "urban factor".

Lave lists and discusses the following factors that might affect mortality: (a) physiological characteristics which include age, sex, race, and genetic factors; (b) socioeconomic characteristics which include income, occupational mix, and fuels used for home heating; (c) environmental factors that include air pollution, radiation, and climatological factors; and (d) personal factors that include smoking habits, habits of exercise, medical care received, and general nutrition.[71] As Lave says almost in despair, "It is virtually impossible to account for all possible factors that might be the 'real' causes of ill health."[72]

INDIVIDUAL STUDIES

Even given the empirical problems, several notable attempts have been made to quantify the health costs attributable to air pollution. It appears that until 1970, Ridker (1967) had made the only significant published attempt to estimate the health costs due to air pollution. Since then, Riggan (1970) has estimated the health costs associated with automotive emissions. And, a study underway in the Environmental Protection Agency is attempting to estimate morbidity costs associated with a pollution composite of sulphur dioxide, total suspended particulates, and suspended sulfates. Finally, estimates of mortality costs associated with air pollution have been developed by Lave and Seskin (1970).

The studies by Ridker, Riggan, and the EPA follow the damage factor method where: (a) an estimate is made of the value of total health losses; (b) a proportionality factor is determined for the share of this value attributable to air pollution; and (c) the product of total health losses times this factor yields the value of health losses associated with air pollution.

In all three studies, the proportion of health losses associated with air pollution is determined to be a constant. Thus, the cost-of-pollution function for health may be taken to be linear with a negative slope. This assumption should be interpreted as an approximation over a limited range of a much more complex function. By assuming that a marginal improvement in health has a constant price over the estimated range of the damage function, the linear damage function gives rise to a linear benefit function.

Ridker - Morbidity and Mortality, Respiratory Diseases

The earliest known published attempt at estimating health costs resulting from air pollution is that of Ridker (1967). For the year 1958, he estimated the total national cost of morbidity and mortality for diseases associated with the respiratory system. The diseases considered were cancer of the respiratory system, chronic and acute bronchitis, pneumonia, emphysema, asthma, and the common cold. These diseases were chosen on the basis of crude empirical determinations and on a priori knowledge.

The cost estimates for each disease included the costs of premature death and burial, treatment costs, and costs associated with absenteeism. The costs of dying earlier than expected were estimated by the 1958 present value of lost future earnings. To put earnings on an annual basis, discount rates of 5 and 10 percent were applied to expected lifetime earnings, assuming full labor force participation. Costs of premature burial represented the difference between the present costs of burial and the present value of future expected burial costs discounted at rates of 5 and 10 percent. Treatment costs were estimated for each disease using per capita expenditures of drug manufacturers' shipments. Absenteeism costs were the product of days lost for each disease and the average annual earnings of those suffering from that disease. Summing the costs for 1958 (using a discount rate of 5 percent) yielded a total economic cost of these diseases of $1.99 billion. Table 5 presents Ridker's results.

Table 5. COSTS OF DISEASES ASSOCIATED WITH AIR POLLUTION

Type of cost	Costs[a] associated with selected diseases, $ million							
	Cancer of the respiratory system	Chronic bronchitis	Acute bronchitis	Common cold	Pneumonia	Emphysema	Asthma	Total
Premature death	518	18.0	6.0	na[b]	329	62	59	992.0
Premature burial	15	0.7	0.2	na	13	2	2	32.9
Treatment	35	89.0	na	200	73	na	138	535.0
Absenteeism	112	52.0	na	131	75	na	60	430.0
Total	680	159.7	6.2	331	490	64	259	1,989.9

[a] Using a discount rate of 5 percent.

[b] Not available.

Source: Ronald G. Ridker, Economic Costs of Air Pollution, New York: Frederick A. Praeger, 1967.

Ridker estimates that 18 to 20% of the approximate cost of $2 billion in national health costs for respiratory diseases are due to air pollution. His proportionality factors of 0.18 and 0.20 represent the proportion of health losses attributable to air pollution. These coefficients are taken from two studies relating, in one case respiratory mortality rates and, in the other, lung cancer mortality rates, to urban and rural areas. The coefficients are corrected for age, sex, race, smoking habits, and the proportion of U.S. population which is urban. Thus, the damage to health from air pollution in 1958 was estimated to be about $.4 billion.

Ridker considers the estimate to be quite conservative. For one thing, he recognizes the absence of avoidance costs representing the moving costs and possibly reduced earnings of those who migrate to areas of lower pollution because of their health. He did not impute the full value of housewife services lost due to death or illness related to air pollution. Nor was any attempt made to include any psychic costs associated with death or illness. Data limitations prevented estimates of full costs for some of the diseases considered and also prevented the consideration of certain diseases.

Full recognition is given to the inability to relate damages to specific types of pollution, thus preventing the construction of individual damage functions.

Riggan - Human Health and Motor Vehicle Pollution

Where the Ridker study will allow for estimation of the economic benefits to be derived from the abatement of air pollution, Riggan (1970) takes a more limited view. Riggan's study was not designed to generate national estimates of total health costs, but rather to investigate the economic costs of motor vehicle pollution on human health and the resulting losses to the Federal Government. In using the same general method as Ridker, Riggan estimates the value of income taxes that would have been paid to the Federal Government by people who died prematurely from automotive and related pollution. His total was $1.9 billion for 1970. He estimates the value of social security payments to workers disabled by automotive pollution to be $189.4 million. Riggan also estimates a value of $97.1 million in lost productivity by

Federal workers in Washington, D.C., due to oxidant-causing eye irritation. His total dollar health cost attributed to motor vehicle pollution is estimated at $2.2 billion.

The study by Riggan is fraught with empirical problems, and it lacks a sound theoretic rationale. The methods used to derive the pollution coefficients that are applied to the total disease categories, are not clear. With respect to the theoretical problems, neither is it clear what a "cost to the Federal Government" really means. It can be argued that the author should have included estimates of the social security disability payments that the Government "saved" because of premature death. This inclusion might have forced the net cost down to the break-even point where the Federal Government neither lost nor gained because of pollution from automobiles and other related pollution. Therefore, the results from this study are not used in this report to generate a national damage estimate for health.

Jaksch - Morbidity and Air Pollution in Portland, Oregon

Jaksch's (1972) study in Portland, Oregon, is a good example of a thorough morbidity-air pollution study that presents an economic-theoretic rationale for estimating health costs of air pollution. Using multivariate regression techniques, Jaksch attempted to isolate the effect of air pollution on the consumption of medical services by enrollees in the Kaiser pre-paid health plan. His supposition was that air pollution (suspended particulates in this case) can aggravate a state of health resulting in increased consumption of outpatient medical services, and in an increase of the number of contacts with the medical system, for certain respiratory, cardiovascular, and other diseases aggravated by air pollution. By considering a host of explanatory variables for pollution exposure, personal attributes, socioeconomic-demographic characteristics, and meteorological parameters, Jaksch was able to isolate suspended particulates as having some effect on the consumption of outpatient medical services used to treat diseases.

EPA - Morbidity, Selected Respiratory Diseases

In a study[73] being performed within the Environmental Protection Agency, research findings from the Community Health and Environmental Surveillance System (CHESS) Program[74] are being evaluated to determine the cost of selected adverse health effects associated with the pollution composite, sulfur dioxide-total suspended particulates-suspended sulfates. The following adverse health effects, which are associated with exposures to these air pollutants, are included in this study: acute lower respiratory disease and chronic respiratory disease.

The methodology employed in this EPA health study involved four steps. First, the impact of these air pollutants on disease rates was determined by statistical analyses of data collected from a number of CHESS communities offering different pollutant gradients. These communities were specifically selected to control for major co-determinats that might affect disease rates. Second, results of the association between these air pollutants and ill health were extrapolated to other Standard Metropolitan Statistical Areas on the basis of relative pollution gradients. Third, the population affected was estimated by using disease rates provided by the National Center for Health Statistics, DHEW. Fourth, average per-case-costs were then applied to rough estimates of the affected population to determine the gross disease-specific costs. The following costs are being evaluated: (1) the direct medical expenditures for doctor visits, medicine, etc.; (2) work loss days; (3) housewife bed disability days; and (4) school loss days.

The objective of the EPA health study is to estimate the benefits of reducing in one case sulfur dioxide and particulates to levels of the primary air quality standards, and in the case of sulfates, to an assumed annual average standard of 6-8 $\mu g/m^3$. There are obvious pitfalls associated with translating risk factors, severity-of-disease rates and average per-case-costs of selected diseases into economic estimates. Yet, such information on health costs should improve our understanding of the potential health benefits to be realized by abating such air pollution.

Lave and Seskin - Mortality

Lave and Seskin (1970) expanded the scope of diseases covered by Ridker (1967). In particular they added air pollution damages to health in the forms of heart disease and cancers of the stomach, esophagus, and bladder. In the case of bronchitis and lung cancer, they consider the evidence relating air pollution and health to be very reliable. Although evidence relating air pollution to heart disease and non-respiratory cancers is not so reliable, they believe that a consideration of all factors suggests causality.

Approximately half the lost income and current medical expenses associated with morbidity and mortality from bronchitis are ascribed to air pollution. The proportionality factor for lung cancer is estimated to be 25%. In the other categories, air pollution is responsible for an estimated 15% of the damages associated with non-respiratory lung cancers, 25% of all respiratory diseases, and 10% of cardiovascular diseases. These coefficients were estimated by regressions that were run on data from published epidemiological studies.

Based on these coefficients, the total annual cost of air pollution in increased human morbidity and mortality can be estimated to be $4.3 billion for 1963;[75] or inversely stated, a 50 percent reduction in air pollution would result in an annual savings of about $4.3 billion. These results are summarized in Table 6.

Table 6. HEALTH COST OF AIR POLLUTION, 1963

Disease Category	$ billion
Respiratory	1.9
Cancers	1.5
Cardiovascular	0.9
Total	4.3

Table 7. FACTORS AFFECTING THE MORTALITY RATE IN U.S. CITIES

$$MR_i = 19.607 + \underset{(2.53)}{.041}\ \text{mean}\ P_i + \underset{(3.18)}{.071}\ \text{min}\ S_i + \underset{(1.67)}{.001}\ P/M^2 + \underset{(5.81)}{.041}\%\ NW_i + \underset{(18.94)}{.687}\ \%\ 65_i + e_i$$

Sensitivity coefficients:	.53%	.37%	.07%	.57%	6.32%

where:

MR_i = the total mortality rate (per 10,000 people) in city i

mean P_i = the arithmetic mean of suspended particulate readings in city i

min S_i = the smallest biweekly sulfate reading in city i

P/M^2 = the population density in city i

% NW = the proportion of the population which is nonwhite in city i

% 65_i = the proportion of the population 65 and older in city i

e_i = an error term for variation in the mortality rate not explained by the equation

Notes: The figures in parentheses are the t statistics for a test that the estimated coefficient is not significantly different from zero (no effect).

The sensitivity coefficients show the expected increase in the mortality rate estimated to come from a 10% increase in each variable in turn.

The equation explains 82.7% of the variation in the mortality rate across 17 cities in 1960.

In their cross-section study of 117 cities, Lave and Seskin (1973) used multivariate regression techniques to explain variation in mortality rates as a function of air pollution, socioeconomic variables, and age. Their regression (Table 7) explains 83% of the total variation in mortality rates for those cities. The regression is a linear equation which predicts the mortality rate within a city on the basis of air pollution, population density, the proportion of non-whites in the population, and the proportion of the population age 65 and older. All coefficients in the regression are shown to be significant.

The "sensitivity coefficient" shows how much the mortality rate would be estimated to increase if one of the variables were to increase by 10%, i.e., if the mean level suspended particulate increased 10%, results show that the mortality rate would increase .53% and a 10% increase in both particulates and sulfur oxides would increase the mortality rate by .90%. Assuming the linear relationship between air pollution (as defined here) and mortality, a 50% decrease in air pollution is associated with a reduction in the mortality rate by 4.5%. Lave concludes that while the individual sensitivity coefficients cannot be argued as "true", their general magnitude cannot be doubted.[76]

For several reasons, Lave and Seskin consider their estimate to be conservative. They argue that for conceptual meaning, the willingness of an individual to pay for improved health or longevity, given a level of income and wealth, is the true measure of health costs due to air pollution.[77] To Lave and Seskin, the sum of income lost and current expenditures resulting from morbidity and mortality caused by air pollution is a gross underestimate of willingness-to-pay. Also, some health costs may have been overlooked, resulting in a more conservative estimate. Finally, the exclusion of some treatment costs results in the underestimation of true damages.

The regression survived a number of tests and manuevers designed to identify any spurious relationships. Air pollution was significant where expected, such as in explaining the mortality rates of the very young, the very old, and people dying of cardiovascular and respiratory diseases. Also, air pollution was not significant where expected, neither in explaining the mortality rates for young adults, nor for people dying from suicide.

NATIONAL ESTIMATE OF HEALTH LOSSES

It is believed that the findings of EPA's CHESS program on morbidity and Lave and Seskin's work on mortality provide an acceptable basis on which a gross damage estimate of the health costs of air pollution can be made. By applying the general methodology utilized in the EPA study to an analysis of the CHESS findings on the health effects of sulfur dioxide, suspended particulates, and suspended sulfates, rough measures of some economic health benefits of controlling these pollutants can be estimated. This crude methodology is outlined in Table 8.

In Table 8 the particular health effects are identified in the different reports from CHESS. Estimates of affected populations are based on: data on populations-at-risk taken from an internal EPA report; data on disease rates published by the National Center for Health Statistics; and, population data recorded in the Statistical Abstract of the U.S.-1972. The estimated change for each health effect is based on an interpretation of the data reported in the individual CHESS studies. Estimates of cost-per-health effect are based upon information taken from the Statistical Abstract of the U.S.-1972 and NCHS reports, tempered with best judgment. Results of this process yield rough estimates of the benefits to human health of controlling sulfur dioxide, suspended particulates, and suspended sulfates. The human morbidity costs for 1970 determined in this manner are estimated to range from roughly $.9 to $3.2 billion.

In extrapolating the Lave and Seskin results, if 1970 air pollution levels (total suspended particulates) were reduced by 26% (in order to reach the primary ambient air quality standard), the savings in morbidity and mortality costs would be $3.73 billion. This was determined here in the following manner: First, Lave and Seskin's regression of air pollution and mortality shows that a 26% reduction in air pollution in major urban areas would lower the mortality rate by 2.33 percent.[78] Second, using cost figures developed by Rice,[79] the value for this percent reduction in mortality and morbidity in 1963 was $2.24 billion.[80] Third, extrapolating this value to 1970, the estimate becomes $3.73 billion.[81]

Table 8. ROUGH ESTIMATES OF SOME HEALTH BENEFITS THAT CAN BE REALIZED BY THE CONTROL OF SULFUR DIOXIDE, SUSPENDED SULFATES, AND SUSPENDED PARTICULATES

Health effect	Rough estimate of population affected,[a] million people	Estimated possible change	Rough estimate of annual health benefits, $ million
Irritation symptoms arising from acute air pollution episodes	50	Symptoms 75-100% eliminated	Not known
Impairment of ventilatory function	50	Subtle improvement[c]	Not known
Symptom aggravation in the elderly	4	On the average 10-30% fewer would report a worsening of symptoms[d]	150-800[e]
Asthma attacks	4	On the average 10-50% fewer asthmatics might report an attack[f]	50-300[g]
Acute lower respiratory	50	Reduction in restricted activity days by 10-40% and physician visits by 20-50%[h]	400-1500[i]
Chronic bronchitis	6	Reduction in prevalence by 20-40%[j]	300-600[k]

(See attached notes)

NOTES ON TABLE 8

a. Populations-at-risk data are taken from: W.C. Nelson, et. al., Estimates of Populations-at-Risk, Environmental Protection Agency, Division of Health Effects Research, Research Triangle Park, N.C., In-House Technical Report, January 1972. Population data are taken from: Statistical Abstract of the United States - 1972 (93rd Edition), U.S. Bureau of the Census, Washington, D.C. Data on disease rates are taken from: Current Estimates from the Health Interview Survey, United States - 1970, U.S. DHEW, PHS, NCHS, Rockville, Md., Vital and Health Statistics, Series 10, No. 72, May 1972.

b. Source: C.J. Nelson, et. al. Family Surveys of Irritation Symptoms During Acute Air Pollution Exposures: 1970 Summer and 1971 Spring Studies. JAPCA 23(2):81-86, February 1973.

c. Source: C.M. Shy, et. al., Ventilatory Function in School Children: 1970-1971 Testing in New York Communities; and C.M. Shy, et. al., Ventilatory Function in School Children: 1967-1968 Testing in Cincinnati Neighborhoods. Both studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS, Environmental Protection Agency, Human Studies Laboratory, Research Triangle Park, N.C. (In press).

d. Source: H.E. Goldberg, et. al. Frequency and Severity of Cardiopulmonary Symptoms in Adult Panels: 1970-1971 New York Studies. In: Health Consequences of Sulfur Oxides: A Report from CHESS.

e. Determined by inflating the estimated health expense for a person with a chronic condition with a limitation in activity (Source: Personal Health Expenses Per Capita Annual Expenses, United States: July-December 1962. Vital and Health Statistics, Series 10, Number 27, February 1966, Table 9, p. 30) to 1970 on the basis of the medical care price index (Source: Statistical Abstract of the United States - 1972, Table 90, p. 65).

f. Source: J.F. Finklea, et. al., Aggravation of Asthma by Air Pollutants: 1971 Salt Lake Basin Studies; and J.F. Finklea, et. al., Aggravation of Asthma by Air Pollutants: 1970-197o New York Studies. Both studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS.

g. Based on a best judgment estimate of $15 per asthmatic attack. This estimate might include the direct cost of medicine and other health services, as well as the cost associated with resultant restricted activity-days.

h. Source: W.C. Nelson, et. al., Frequency of Acute Respiratory Disease in Children: Retrospective Survey of Salt Lake Basin Communities, 1967-1970; J.F. Finklea, et. al., Frequency of Acute Lower Respiratory Disease in Children: et. al., Prospective Surveys of Acute Respiratory Disease in Volunteer Families:

1969-1970 Chicago Nursery School Study; and G.J. Love, et. al., Prospective Studies of Acute Respiratory Disease in Volunteer Families 1970-1971 New York Studies. All of these studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS.

i. Based on the value of $11 for a restricted activity-day. This value is determined by dividing the per capita income in the U.S. for 1970, by the number of days in the year. Data on restricted activity days for acute lower respiratory disease are taken from: Acute Conditions: Incidence and Associated Disability, United States - July 1969-June 1970. Vital and Health Statistics, Series 10, Number 77, Table 2, p. 12; the percentage of these restricted activity days that might be associated with populations within SMSA's are determined from Table 11, p. 21; and the number of physician visits is determined from Table 4 (p. 14) and Table 11 in much the same manner. These physician visits are then valued by dividing the per capita consumer expenditures for physician services (Source: Statistical Abstract of the U.S. - 1972, Table 92, p. 66) by the physician visits per capita (Statistical Abstract of the U.S. - 1972, Table 100, p. 69).

j. Source: D.E. House, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Adults: 1970 Survey of Salt Lake Basin Communities; C.G. Hayes, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Adults: 1970 Survey of Five Rocky Mountain Communities; J.F. Finklea, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Military Recruits, 1969-1970; and, H.E. Goldberg, et. al., Prevalence of Chronic Respiratory Disease Symptoms in Adults: 1970 Survey of New York Communities. All of these studies are in: Health Consequences of Sulfur Oxides: A Report from CHESS.

k. Based on the inflation to 1970 of the annual expense to a person with a chronic condition with no limitation in activity on the basis of the medical care price index (Source: See Note e).

This amount of $3.73 billion includes direct health expenditures and the discounted present value of lost future earnings due to morbidity and mortality. This estimate probably understates the true cost of death caused by air pollution because: (1) since people are valued according to their earnings, a person not earning wages is usually valued at zero; and (2) the willingness-to-pay for improved health normally exceeds the costs incurred for protection and care.[82]

It is possible that Lave and Seskin have stronger faith in the magnitude, sign, and statistical significance of their regression coefficients than what their analysis would seem to support. Their many statements about the causes of these "effects" may not be as justified as they seem to conclude. Some of the difficulties with their work include the use of aggregate correlations, inadequate exposure data, no personal covariate information such as smoking or occupational exposure, and mobility.[83] They are also faced with the obvious problem of regressing aggregated data collected for different reasons. Yet in fairness, despite the author's questionable data and extended discussion of their results, their estimate of health costs is believed to be reasonable.

While Lave and Seskin struggle with the multiple causation dilemma and generally ignore the multicollinearity problem, the CHESS design attempts to separate major co-determinants of disease, primarily through analysis of variance techniques. Multiple, repetitive health, personal covariate, meteorologic, and environmental pollutant exposure measurements were taken in CHESS on tens of thousands of individuals to estimate the relative effects of multiple pollutant exposures. Even though the results seem to be reasonable, several criticisms concerning the CHESS design have been levied. These criticisms relate to the bias in the samples and the argument that significant socioeconomic covariates are not adequately accounted for.

From the extrapolated CHESS data and the Lave-Seskin study, it seems that a defensible estimate of health costs for 1970 can be made. The CHESS data extrapolated in this report estimates morbidity costs associated with selected respiratory diseases. Lave and Seskin's work estimates morbidity and mortality costs associated with the same respiratory diseases that the CHESS study considers, as well as many others. The Lave-Seskin estimate of morbidity costs is inferred from their mortality estimate. In contrast, the CHESS estimate for selected respiratory diseases is based upon direct analysis of morbidity rates and air pollution. Since the CHESS estimate would seem to be a more reliable estimate of those respiratory morbidity costs, it is desirable that this estimate rather than the Lave-Seskin estimate for those same diseases be included in the aggregate health cost estimate.

Thus, in order to make the two estimates additive, the component identified in the Lave-Seskin estimate as morbidity and direct expenditures for respiratory diseases, must be subtracted from the \$3.73 billion. Such an operation results in a health estimate of \$3.51 billion. Given that 73.5% of the total population in 1970 lived in urban areas, this further reduces the estimate of health costs to \$2.58 billion.[84] If then, the variance about the mean is considered, a range of \$0.7-4.4 billion can be generated for 1970. Adding this range of estimates to the range of \$.9-3.2 billion generated by extrapolating the CHESS data, the range of gross estimates of health costs associated with air pollution for 1970 becomes \$1.6-7.6 billion.

This gross health estimate represents the benefits that would be realized by reducing air pollution in major urban areas to the particulate primary standard of 75 $\mu g/m^3$, the sulfur dioxide primary standard of 80 $\mu g/m^3$, and the assumed sulfate standard of 6-8 $\mu g/m^3$. Given the lack of knowledge to the contrary, it is assumed that the estimates generated by the two studies are additive in the sense that they have been handled here. It can be concluded that the middle of the range, \$4.6 billion, is the "best" estimate of the true costs of the adverse effects of air pollutants on human health and longevity.

SECTION VI

ASSESSMENT OF AIR POLLUTION DAMAGE TO MAN-MADE MATERIALS

OVERVIEW OF THE PROBLEM

Air pollution has a variety of effects on materials--the corrosion of metals, the deterioration of materials and paints, and the fading of dyes. There have been a number of attempts at estimating the resultant economic losses due to those detrimental effects of air pollution.

INDIVIDUAL STUDIES

Robbins - Electrical Contacts

It appears that the first materials effects study of major significance was performed by Robbins (1970) of Stanford Research Institute. The study intended to determine whether or not air pollution creates problems of economic significance in the operation of electrical contacts, and if so, to study the cause-and-effect relationships. Information was compiled by searching the literature as well as by consulting manufacturers through letters, telephone calls, and on-site visits. The major costs investigated were: (a) the direct cost associated with the plating of contacts with precious metals; and (b) the indirect cost associated with the preventive measures of air conditioning and air purification.

The types of contacts that are normally plated are used in switches, relays, connectors, potentiometers, and commutators, which are used mostly in the electronics and communications industries. More money is spent combating the effects of sulfur dioxide (SO_2) and hydrogen sulfide (H_2S) air pollution on low-voltage electrical contacts than all the other air pollution effects on electrical devices combined. The effects of organic gases and particulates are of less importance. Organic gases form "frictional" polymers on sliding contacts whereas particulate pollutants are a problem due to the fact that the materials are excellent absorbers of moisture and corrosive agents.

It was estimated that $20 million is spent annually on plating contacts with precious metals because of air pollution, and $25 million is spent annually on air conditioning and purification which act to prevent corrosion by maintaining clean air. Another $4 million is expended annually for washing insulators, $5 million for research and development expenditures by firms that might be affected by air pollution, and as estimated $10 million for losses due to failures. This totals approximately $65 million annually.

The most important conclusion drawn from this study was the fact that the air pollution problem, with respect to electrical contacts, was not as serious as originally estimated. It was also concluded that the cost of $65 million is unnecessarily high because two or more individually preventive measures are being applied simultaneously to minimize losses. It is believed that losses will decrease as cheaper substitutes, more resistant to air pollution, are used in electrical contacts.

ITT - Electrical Components

In a similar survey, ITT Electro-Physics Laboratories (1971) assessed the economic impact of air pollution on electronic components. Information concerning pollutant-material damage mechanisms was acquired by surveying the literature. Interviews with manufacturers and users of electrical and electronic components provided information on actual experience. The electronic component categories studied were: semiconductor devices, integrated circuits, television picture tubes, connectors, transformers, relays, receiving tubes, and crystals. Total damage costs for these receptors summed to $15.5 million. This included $2.36 million for preventive costs which included filtering air, etc., and another $13.2 million for maintenance costs which were the costs of cleaning, repairing, replacing and in any way restoring a piece of otherwise defective equipment. Costs that were estimated for various electronic devices in the Robbins (1970) study were not assessed in the ITT study.

As in the Robbins study, the cost of $15.5 million estimates the cost of two or more individually effective counter-measures that are being applied simultaneously to minimize losses. As expected, the data were very sketchy, and extrapolations from individual cases to the nation are questionable at best. Attempts to correlate statistically equipment failures and pollutant levels were less than successful. While the literature reviews indicated that sulfur dioxide should be expected to account for most of the damage to electrical components, interviews with manufacturers revealed that particulate matter was perhaps responsible for most of the electronic component and equipment malfunctions currently experienced.

Salmon - General Materials

The most comprehensive survey of the economic effects of air pollution on materials was undertaken by Richard L. Salmon (1970) of Midwest Research Institute. The objectives of the study were: (1) to identify the materials, air pollutants, and environmental factors that should be studied in order to assess the economic damage to materials caused by air pollution; (2) to analyze systematically the physical and chemical interactions among the variables identified in (1) for the purpose of determining cause-effect relationships; (3) to determine, where possible, the pollutant dose-response relationship for materials that are significant because of their relative economic value, and indicate how this may be done where such relationships are presently defined; and (4) to translate the pollutant and dose-response relationship into a pollutant and dose-cost-damage function.

Information was gathered through literature searches, and by personal, mail, and telephone interviews. Economic losses of materials were attributed either to damaged properties or to reduced serviceability. The basic problem was to determine the extent of economic damage associated with a given level of physical or functional damage. This problem was approached in different ways, depending on the material and its application. In some cases, a "percent condition" approach was adequate, with economic damage considered to be incurred at the same rate as the physical damage. The replacement of damaged materials was also included in this category, with replacement presumably occurring at the 100% damage (or zero percent condition level). In other cases, a cost-of-prevention or cost-of-restoration basis proved more suitable.

The economic value of material exposed to air pollution was calculated as the product of the annual dollar production volume times a weighted average economic life of the material (based on usage), times a weighted average factor for the percent of the material that is exposed to air pollution. The in-place or as-used value of the material was determined by including a labor factor. The rate of economic loss was calculated as the product of the economic value of material exposed to air pollution times a value of interaction. The value of interaction was calculated by estimating the difference between the rate of material deterioration in a polluted environment compared to that in an unpolluted environment. The interaction value is expressed as dollars lost per year. The results of the operations described are presented in Table 9. The total value of materials exposed to air pollution and values of interaction between the various materials and pollutants have been combined to produce a single figure representing the extent of economic damage attributable to air pollutants.

To interpret the results in Table 9, it must be realized that the individual material loss estimates were made to determine relative importance rather than actual value. However, the sum of the economic losses, $3.8 billion in 1968, appears tenable. Such a calculation procedure is valid only within narrowly circumscribed limits. The difficulties lie in the problems inherent in the technical coefficients approach--the substitution problem in particular. The study concluded that if it is assumed that this list of materials represents only 40% of the total value of materials exposed to air pollution, and that damage functions for the other 60% are similar, the total loss due to chemical attack on materials by air pollution is estimated at $9.5 billion.

Salmon found that the pollutants, in decreasing order of economic importance, and the materials they damage, are as follows:

1. Sulfur oxides: metals, cotton, finishes, coatings, building stone, paints, paper, and leather.
2. Ozone: rubber, dyes and paints.
3. Nitrogen oxides: dyes and paints.
4. Carbon dioxide: building stone.
5. Particulates: stone, clay, and glass

Table 9. RANKING OF MATERIAL ECONOMIC LOSSES CAUSED BY DETERIORATION

Rank	Material	Economic loss, $ million
1	Paint	1,195.0
2	Zinc	778.0
3	Fibers	358.0
4	Cement and concrete	316.0
5	Nickel	260.0
6	Rubber	194.0
7	Tin	144.0
8	Plastics	126.0
9	Aluminum	114.0
10	Copper	110.0
11	Carbon steel	53.8
12	Building brick	24.2
13	Paper	22.1
14	Leather	20.6
15	Wood	17.6
16	Building stone	17.6
17	Brass and bronze	13.4
18	Magnesium	13.0
19	Alloy steel	8.7
20	Bituminous materials	2.2
21	Gray iron	1.9
22	Stainless steel	1.6
23	Clay pipe	1.4
24	Malleable iron	0.9
25	Chromium	0.8
26	Silver	0.7
27	Gold	0.6
28	Glass	0.3
29	Lead	0.2
30	Molybdenum	0.1
31	Refractory ceramincs	0.02
32	Carbon and graphite	0.003
Total (Approximate)		3,800.0

It was concluded that organic pollutants (hydrocarbons and aldehydes) are not damaging to materials except, to some extent, to elastomers. Much information was available on the effects of air pollutants on metals and rubber. There was some information on fibers such as cotton and nylon and little on paints, paper and leather. Virtually no information existed on plastics, wood, wool, and concrete. There exist direct quantitative correlations of damage with specific pollutants (dose-response) only for zinc and SO_2, several varieties of rubber and O_3, and for cotton and SO_2. In summary, the major informational shortages concern the effects of air pollution on concrete, paints, fibers, and plastics.

The Salmon (1970) study is useful in summarizing the effects of air pollution on materials and lays the groundwork for more intensive studies. Some of the data used, such as that for formulating interaction and corrosion rates, is of questionable validity, and particularly in a quantitative analysis such as was used here, the results are only as good as the data used. Another problem exists because no clear distinction was made between the stock and flow of materials. There is very likely a mixture of the two, resulting in potential discounting problems. Also, only the direct effects were investigated; the "value" of service was not assessed. As Salmon cautioned in his report, the economic loss from material deterioration indicated susceptibility to economic loss or potential loss. The results could not be interpreted as actually incurred economic loss. A primary purpose of the study was the ranking of materials indicating relative measures of air pollution-induced damage. This study should be very useful for setting research priorities.

Mueller and Stickney - Rubber Products

The Battelle Memorial Institute study by Mueller and Stickney (1970) entitled, "Survey and Economic Assessment of the Effects of Air Pollution on Elastomers," correlates technical information relating to the effects of air pollution on rubber products and makes an estimate of the yearly cost of this pollution. Costs are measured as: (1) the increased costs at the manufacturers' level to provide products that are resistant to atmospheric pollutants (these are normally passed on to the consumer); and (2) the direct costs to the consumer in the form of shortened useful life of the product. The combined costs at the consumer level are used in estimating the total cost of pollution.

One phase of the study was a review of the literature for technical information. In the second phase questionnaires were sent to 60 rubber products firms to determine the cost of atmospheric pollution at the manufacturing level. Of the thirty which were returned, only about a third provided complete information.

To estimate the cost of atmospheric pollution at the rubber product manufacturer's level, two independent calculations were made. One was based on the information derived by questionnaires sent to the industry, whereas the second calculation was based on the total of individual compounding costs.

Extrapolation of the results recorded by individual firms to the industry as a whole show a yearly cost of $54.0 million due to the detrioration of rubber products caused by air pollution. To calculate the added cost at the manufacturer's level, it was necessary to add individually estimated costs for resistant polymers, antiozonants, waxes, protective finishes, and wrapping. These estimated costs are listed in Table 10.

Table 10. ESTIMATED COSTS OF AIR POLLUTION RESISTANT MATERIALS

Preventive measure	$ million
Resistant polymers	20.6
Antiozonants	34.1
Waxes (50% of total)	5.0
Protective finishes	?
Wrappings	?
Research for compounding	?
Total	59.7

It can be seen that the two figures of $54.0 million and $59.7 million compare favorably. These are costs at the manufacturer's level. Since industry estimates suggest that an average retail price is three times the manufacturing cost, the compounding cost would be approximately $160-180 million at the retail level. Information on the cost of early replacement of rubber products is summarized in Table 11.

Table 11. COSTS OF SHORTENED LIFE OF RUBBER PRODUCTS

Rubber product	$ million
Tires	37.0
Innertubes	-
Footwear	-
Mechanical goods	29.7
Medical goods	100.5
Belting	22.5
Hoses	36.0
Total	225.7

The total annual cost of pollution, as it affects the rubber industry, is approximated as the sum of $170 million (the middle of the range $160-180 million) and $225.7, or about $395 million. The first cost is that added at the manufacturer's level, which is passed on to the consumer in the form of an increased price for the product. The second costs is for the early replacement of rubber products because of a shortened service life, a cost which must be borne directly by the consumer. Another cost considered is the labor cost connected with the early replacement of damaged rubber products. Mueller and Stickney conservatively estimate this labor cost to be $75 million annually.

In conclusion, almost all damage to rubber is caused by ozone. Very little is known about effects of other pollutants on elastomers. Virtually no information is available on the damage threshold for rubber, so that few or no data are available for the construction of a meaningful damage function.

The Mueller-Stickney study lacks detail in that it deals mostly with gross figures. Early replacement and associated labor costs of rubber products were "ballpark estimates" at best. Also, the logic of the assumption that retail costs are three times the manufacturers' cost can be questioned. Theoretically, the pollution cost at the retail level should only reflect the incremental pollution-related costs at the manufacturing level. It is not clear that the additional cost imposed by air pollution necessarily result in an increase in overhead and marketing costs or any other costs comprising the factor of "three times." Nonetheless, given the lack of better information, the estimate of $475 million annual cost determined by Battelle is considered acceptable in this report.

Spence and Haynie - Paints

Recent work by Spence and Haynie (1972) investigated the deterioration of exterior paints by: (1) particulate matter primarily; and (2) the interaction of particulate matter and sulfur oxides. The associated potential economic loss to manufacturers and consumers because of this deterioration was then estimated. Their initial review of the literature made them acutely aware of the almost total lack of information on dose-response relationships with respect to air pollution damage to paints. This informational gap confirms the findings of the Salmon (1970) study mentioned earlier. That study concluded that sulfur dioxide and particulate matter play an important role in the chemical deterioration of modern-day exterior paints. These pollutants serve to promote the chemical deterioration of exterior paints.

Spence and Haynie referred to the soiling studies by Michelson and Tourin (1967 and 1968) and Booz, Allen and Hamilton (1970) in order to derive information on the frequency of house repainting as a function of suspended particulate concentrations. The results of Michelson and Tourin are summarized in Table 12, and Booz-Allen in Table 13. In Table 12, it is shown that the maintenance intervals of the years between repaintings were observed to decrease as the particulate concentrations increased. While there appears to be a positive relationship between frequency of repainting and particulate concentrations, the questionable data generated in the Michelson and Tourin study (see Section IX) make use of it questionable.

Table 12. INTERVAL FOR EXTERIOR REPAINTING AS A FUNCTION OF PARTICULATE CONCENTRATIONS*

City	Particulate concentration, μg/m^3	Maintenance interval, year	Maintenance frequency, number/year[a]
Steubenville	235	0.88	1.14
Uniontown	115	1.89	0.53
Suitland	85	2.93	0.34
Rockville	75	3.62	0.28
Fairfax	60	3.90	0.26

[a] Reciprocal of maintenance interval in years

* Source: J. W. Spence and F. H. Haynie. Paint Technology and Air Pollution: A Survey and Economic Assessment. Environmental Protection Agency Publication No. AP-103, Research Triangle Park, N. C. (February 1972).

Table 13. FREQUENCY FOR EXTERIOR WALL PAINTING IN PHILADELPHIA AS A FUNCTION OF PARTICULATE CONCENTRATION*

Particulate concentration ranges, μg/m^3	Mean annual frequency	Standard error of mean
<75	0.28	0.016
75-100	0.35	0.053
100-125	0.35	0.041
>125	0.29	0.055

* Source: J. W. Spence and F. H. Haynie. Paint Technology and Air Pollution: A Survey and Economic Assessment. Environmental Protection Agency Publication No. AP-103, Research Traingle Park, N. C. (February 1972).

Many of the analytical and statistical problems encountered in the Michelson studies were minimized in the Booz, Allen, and Hamilton study in Philadelphia. Table 13 shows their maintenance frequencies for exterior wall painting by mean annual particulate concentrations. Spence and Haynie suggest that the fact that the proportion of households with incomes less than $6000 increased with pollution level is a factor that tends to counteract the effect of suspended particulates on paint life. And it is this confounding factor that partially explains why no statistically significant difference in painting frequency as a function of particulate level was detected.[86]

Table 14 outlines the method used by Spence and Haynie to establish their estimate of the potential annual consumer cost for repainting that can be attributed to pollutant damage in urban areas. Estimates of losses are developed for four paint classes: coil coating, automotive refinishing, maintenance, and household. Expected service lives were best "guesstimates" except for household, where expected service lives for rural and urban areas were estimated from the Michelson and Booz-Allen studies. Estimates of the distribution of paint in rural versus urban areas were also best judgments of the authors. Labor factors were estimated from best available information concerning professional painting costs. The total value lost at the retail level is estimated as $704 million. Household paints, with a value loss of $450 million, represent over 75% of the total estimate.

The authors readily admit that these calculations result in only a rough approximation, and that more information on dose-response, expected service life, maintenance frequency, and labor factors, must be obtained if more reliable economic assessment is to be made. Given the lack of better information, the figure of $0.7 billion will be taken as more defensible than the estimate for paint damage of $1.195 billion generated in the Salmon study.

Fink - Corrosion

A recently completed study by Fink, Buttner, and Boyd (1971) attempted to develop a more realistic assessment of the added cost of corrosion damage to the nation resulting from the exposure of metallic systems and structures to polluted atmospheres. In the approach used, applicable national shipment/

Table 14. ECONOMIC ASSESSMENT OF AIR POLLUTION DETERIORATION OF EXTERIOR PAINTS*

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12
Exterior paint classes	Value at manufacturer's level, $ million	Area	Expected service life, years	Maintenance frequency,[a] per year	Estimated distribution of paint, % population	Paint consumed in urban areas,[b] %	Value of paint exposed in urban areas, $ million	Service life,[c] % loss	Loss at manufacturer's level, $ million	Labor factor	Loss at consumer's level, $ million
Coil coating	40	Rural Urban	20 15	0.05 0.07	30 70	77	31	25	8	2	16
Automotive refinishing	150	Rural Urban	5 4	0.2 0.25	30 70	74	111	20	22	4	88
Maintenance	100	Rural Urban	5 4	0.2 0.25	30 70	74	74	20	15	4	60
Household	485	Rural Urban	6 3	0.17 0.33	40 60	74	359	50	180	3	540
Total	775						575		225		704

Notes:

[a] Maintenance frequency is the reciprocal of expected service (Column 4).

[b] Calculation of % coil coatings consumed in urban areas (Column 7):

$$\begin{array}{lccc} & \text{Col. 5} & & \text{Col. 6} \\ \text{Rural Areas:} & 0.05 & \times & .30 = 0.015 \\ \text{Urban Areas:} & 0.07 & \times & .70 = 0.049 \\ & & & \overline{0.064} \end{array} \qquad \frac{0.049}{0.064} \times 100 = 77\%$$

[c] Calculation of % service life loss for coil coating (Column 9):

Rural Areas: 20 years
Urban Areas: 15 years

% Service Life loss:

$$\frac{20 - 15}{20} \times 100 = 25$$

* Source: J. W. Spence and F. H. Haynie. Paint Technology and Air Pollution: A Survey and Economic Assessment. Environmental Protection Agency Publication No. AP-103, Research Triangle Park, N.C. (February 1972).

value data from the U.S. Department of Commerce were employed to compute average pollution costs on a national basis. Of these data, individual corrosion costs were calculated for nine major categories that survived the screening process (see Table 15). These categories were regarded as the most sensitive to and most damaged by air pollution corrosion. The total of these individual estimates was $1.45 billion.

Two calculations were considered by Fink et. al. for assuming up the economic marginal cost of corrosion caused by air pollution over the typical cost in clean air service. The first calculation estimated the extra amount of protection and maintenance expense required in polluted atmospheres to prevent serious corrosion attack. The second calculation estimated the cost due to the shortened life of the structural system caused by corrosion from polluted air. Thus, costs associated with corrosion include both maintenance costs (i.e., painting) and early replacement costs.

The general approach compared maintenance painting costs in clean and polluted air. The steps followed were: (1) the total amount of each item in use was established; (2) this amount was converted into exposed surface area; (3) the portion of this area exposed to polluted air was estimated; (4) the annual extra cost of protection by paint, per unit area, was calculated for each system; and (5) the area and annual cost figures were combined to obtain the total national loss for each item.

As shown in Table 15, the top four structural systems are primarily constructed of galvanized steel. Based on this corrosion study, the accelerated corrosion of zinc by sulfur dioxide accounts for more than 90% of the national economic burden imposed by air pollution corrosion.

The Fink, et. al. corrosion study makes a systematic and reasonable estimate of the costs of corrosion to materials and the costs of related losses. Yet, several criticisms can be levied against this study. The first criticism relates to the problem that typifies most materials studies: no attempt is made to relate material damage to actual levels of air quality. Material losses are identified with "clean" or "polluted" areas which are not defined according to the severity or kind of air pollution. As a general rule, any study of air pollution damage should attempt in its analysis to relate damages to actual

Table 15. ANNUAL COST OF CORROSION BY AIR POLLUTION DAMAGE OF EXTERNAL METAL STRUCTURES, 1970*

Structural System	Useful life, years	Cost basis	Cost, $ million	Percent of total
Outdoor metal work	45	Maintenance	914.0	63.0
Chain link fencing	30/20	Maintenance	166.0	11.5
Pole line hardware	30	Replacement	161.0	11.1
Galvanized wire and rope	20	Replacement	112.0	7.7
Steel storage tanks	50/11	Maintenance	46.3	3.2
Bridges	30	Maintenance	30.4	2.1
Street light fixtures	20	Maintenance	11.9	0.8
Power transformers	30	Maintenance	7.5	0.5
Transmission towers	30	Maintenance	1.5	0.1
Total			1,450.0	100.0

*Source: F.W. Fink, F.H. Buttner and W.K. Boyd. Technical Economic Evaluation of Air Pollution Corrosion Costs in Metals in the United States. Final Report from Battelle Memorial Institute, Columbus, Ohio, to the EPA, Research Triangle Park, N.C. February 1971.

levels of air quality, or at least to sound proxy for air quality. The use of "clean" and "polluted" as measures of the severity of air pollution, without further definition, is not acceptable. Another problem in the Fink corrosion study is the fact that the role of relative humidity in the corrosion and deterioration of materials is not considered in the analysis. Such an important parameter cannot be ignored.

Gillette - SO_x Effects on General Materials

Gillette (1973), employing basically the same general approach as that used by Battelle, attempted to rectify in his assessment of materials damages, some of the problems in the Fink study. Gillette's study, being somewhat broader than that of Battelle, was designed to assess the economic damages from sulfur oxides (SO_x) to man-made materials. Where Fink assumes that about 80% of materials are located in "polluted areas," Gillette assumes that materials are distributed according to human population. Information on population distributions, coupled with sulfur dioxide data for about 150 SMSA's for the years 1968-1972, provided a basis for estimating materials populations-at-risk.

Gillette then integrated measures of the average annual relative humidity by SMSA into his analysis. This consideration of relative humidity is important because the corrosion damage function shows relative humidity to be more important than sulfur dioxide in causing corrosion. Using the best available damage function data for corrosion and paint deterioration, Gillette estimated economic losses for the inclusive years. Gillette estimated for 1970 that SO_x damage (where sulfur dioxide acts as a surrogate for all sulfur damaging compounds in the atmosphere) to metals and paints was approximately $.4 billion. Gillette concluded from his analysis of available dose-response data on the effects of SO_x on susceptible materials that SO_x effects on textiles, building materials, leather and paper products, and dye fading are probably negligible from an economic standpoint. Gillette based this conclusion on the following considerations: (1) many materials are exposed primarily to indoor environments where the exposure is to much lower levels of air pollutants than exposure outdoors; (2) current SO_2 levels are generally lower than several years ago, presumably because of the substitution of cleaner fuels; and (3) the use-life of many materials is quite short.

Gillette's study, while a substantial improvement upon earlier efforts to assess materials losses due to air pollution, is not necessarily a definitive statement of the effects of sulfur oxides and derivatives on man-made materials. For example, it is difficult to say to what extent SO_2 is a good surrogate for all atmospheric sulfur-damaging compounds. It is possible that atmospheric sulfates are significant in the deterioration of materials, and thus, should have been accounted for in a more explicit manner in Gillette's analysis. Also, it appears that in some cases, tenuous conclusions were drawn where informational gaps existed. For example, some of the assumptions made concerning the paint damage function were based on very "soft" information. Yet even with these caveats, the estimate of SO_x-caused material losses developed by Gillette is believed to be more realistic and more defensible than estimates of losses developed in other materials studies.

Salvin - Dye Fading

Victor S. Salvin (1970) of the Unitersity of North Carolina conducted a study of the economic effects of air pollution on textile fibers and dyes. The objectives of his study were: (1) to conduct a comprehensive survey to identify and document known and suspected air pollution-induced effects on various textiles and dyes; and (2) to assess the economic effects of air pollution on textile fibers and dyes.

The status of the problem was discussed with manufacturing and industrial representatives as to the prevalence, mechanisms, prevenative measures, and research costs. The suppliers of dyes were contacted for costs of dyes and dyeing processes (preventative measures). A technology committee of each industry served as a clearinghouse for information. The production figures for each industry, the awareness of the industry, and actions by major manufacturers in offering goods of increased performance were documented. The costs in this case are those of research, quality control, more expensive dyes and textiles, and the associated, more costly production techniques. The additional annual replacement costs of air pollution-damaged textile and fiber products were also estimated. Preliminary economic costs of the fading of dyes on textiles due to air pollutants are shown in Table 16.

Table 16. ESTIMATED COSTS OF DYE FADING IN TEXTILES

Pollutant	Effect	$ million
NO_x	Fading on acetate and triacetate	$ 72.800
	Fading on viscose rayon	21.600
	Fading on cotton	22.050
	Yellowing of white acetate-Nylon-Spandex	5.650
	Subtotal	$122.100
O_3	Fading on acetate and triacetate	24.985
	Fading on Nylon carpets	41.500
	Fading on permanent-press garments	17.050
	Subtotal	83.535
	Total	$206.000

The costs of fading of dyed fabrics by oxides of nitrogen (NO_x) and ozone (O_3) generally are based on: the increased cost of dyes more resistant to fading; the cost of inhibitors for cheaper dyes; the cost of research; the cost of quality control related to the use of more expensive dyes; and, the costs to consumers and sellers with respect to any reduction in product-life.

As weak as this information is, it appears as if this is the only information of its type available. There are little or no supporting economic data and none that would contribute to the construction of any damage function. Given the serious concern over the validity of many of the assumptions made in his study, it is believed that the estimate of $206 million is a very rough approximation of the actual damage of air pollution on textile and fiber products. The conservative nature of this estimate of corroborated by the absence of data in Salvin's study on the effects of sulfur and nitrogen oxides and acids and other particulate matter on the deterioration of textile fibers and dyes.[87] These effects are assumed to be measured in the "fibers" category in Table 9.

NATIONAL ESTIMATES OF MATERIALS LOSSES

The eight studies reviewed in this report offer substantial evidence on which a reasonable national gross damage estimate can be based. A total of $1.8 billion is derived if the following are summed: $.5 billion (rounded off) from the Mueller and Stickney elastomer study; $.4 billion from the Gillette SO_x study; $.2 billion from the dye-fading study; and $.7 billion from the Spence-Haynie paint study. In summing these, it is assumed: (1) that the Gillette study is more defensible than the corrosion study by Fink, et. al.; (2) that the Gillette study does not significantly overlap with the Spence-Haynie study that focuses primarily on the effects of particulates on painting rates; and (3) that the Gillette study adequately accounts for damages to electrical contacts and components. Then if the materials analyzed in these studies--zinc, paints, synthetic and natural rubber, carbon and alloy steel, fibers, cement and concrete, plastics, building brick, paper, leather, wood, and building stone--are subtracted from the Salmon study, in addition to the metal categories of aluminum, copper, stainless steel and lead which were regarded by Fink, et. al. as not significantly affected by air pollution, the total remainder in the Salmon study becomes about $.4 billion. Adding $.4 billion to the $1.8 billion derived earlier, the total gross damage estimate for material losses in 1970 due to air pollution is approximated at $2.2 billion.

The Salmon study develops estimates of losses for the various material receptor categories, but where more indepth research was done, it is believed that those estimates should be given priority. It should be reasonable to assume that this national estimate of materials losses is representative only insofar as it falls within an estimated range. Given the lack of more objective evidence, the percent variation expressed with the property value estimate will also be applied to the materials receptor. By applying that same variation (about 43%), a range of $1.3-3.1 billion is generated, with a "best" estimate of $2.2 billion. Given the nature of the studies reviewed, this estimate should be viewed not as the "true" cost of material damage but indicative of the general magnitude of damage in 1970.

SECTION VII
ASSESSMENT OF AIR POLLUTION DAMAGE TO VEGETATION

OVERVIEW OF PLANT SURVEYS

Damage to vegetation as a result of air contamination has been recorded in the United States since the turn of the century. What was once a problem associated only with point sources has evolved into an air pollution problem more commonly associated with urban expansion. The continued commercial and noncommercial production of crops and forests in many areas has been jeopardized and in some locations discontinued.

In general, air pollution adversely affects plants in one of two ways. Either the quantity of output or yield is reduced or the quality of the product is lowered. The biological response of a plant to a fumigation by air pollution is a function of a complex mix of biological, environmental, and climatic factors. Such factors include, among others: level and duration of pollution exposure, age of plant, genetic sensitivity of the plant, light, relative humidity, soil moisture and fertility, and general health of the plant. Given this kind of information, one could construct a reasonable, physical dose-response relationship--the physical damage function. The translation of this function into an economic damage function is fraught with another complex set of variables. Important aspects that one must consider here include: time and growing season, market value of the plant affected, the aesthetic value that might be attached to the plant, the nature of the harvesting and culturing costs for the particular affected crop, the adaptability of the site for growing a different crop, and the value of the site for alternative uses.

Two general approaches have been used to assess the amount of economic loss resulting from plant damage by air pollution. One general approach has been to survey air pollution losses on a statewide basis by using the existing manpower of county agricultural agents and commissioners at the local level. From these local estimates of damage, extrapolations can be made to the national level to arrive at a crude estimate of gross damages. Another general approach is one of incorporating data on pollutant emissions, crop statistics, and meteorological parameters into a predictive model of plant losses. Such models that incorporate damage factors are then subject to continual refinement as: (1) greater knowledge about dose-response relationships is gained; and (2) the true situation at the local level is better defined.

The major strengths in using statewide surveys are: (1) an existing manpower can be utilized for achieving continual coverage over an area; (2) agents at the local level have an established rapport with growers in that area, are familiar with any crop peculiarities, and are probably knowledgeable of any sources of pollution in the locale; and (3) a field coordinator supplies expertise to the reporters and provides some degree of standardization in reporting losses. One problem arises all too often: unjustifiable conclusions can be made on one-year estimates when several years are needed to make accurate assessments of damages.

INDIVIDUAL STUDIES

Middleton and Paulus - California, 1955

The use of manpower at the local level was first used in a California survey performed in 1949. A second survey in 1955, as reported by Middleton and Paulus (1956), was designed to determine the location of injury, the crops injured, and the toxicant responsible for the damage. Specialists in agriculture throughout the state were trained as crop survey reporters. The survey covered four categories of crops: field, flower, fruit, and vegetable.

Lacasse - Pennsylvania, 1969 and 1970

A similar program was established in 1969 in Pennsylvania and reported by Lacasse-Weidensaul-Carrol (1970). As in California, a training course was held to teach trained observers how to identify and evaluate air pollution damage to plants. The objectives of the survey were: (1) to estimate objectively the total cost of agricultural losses due to air pollution in Pennsylvania;

(2) to determine the relative importance of the various pollutants in Pennsylvania; (3) to survey the extent of the air pollution problem in Pennsylvania; and (4) to provide a base for estimating the nationwide impact of air pollution on vegetation and for guiding research efforts.

A professional plant pathologist was enlisted to coordinate the field survey. He assisted reporters in the detection and evaluation of air pollution damage to crops and performed independent field surveys in areas where sources of pollution were located. Commercial and noncommercial plants were studied. Past episodes also were investigated for purposes of detecting possible trends. Estimates of losses were based on the amount of plant damage, crop value, and production costs incurred by harvest time. Direct losses to producers or growers included only production costs. Indirect losses included profit losses, costs of reforestation, grower relocation costs, and substitution of lower-value crops for higher-value crops. Costs associated with the destruction of aesthetic values, erosion, and resultant stream silting, damage to watershed retention capacity, and farm abandonment, were not considered.

Ninety-two field investigations were made as part of the Pennsylvania study. The amount of direct losses uncovered in the survey were estimated at more than $3.5 million. The air pollutants, by decreasing importance, were: oxidants, sulfur oxides, lead, hydrogen chloride, particulates, herbicides, and ethylene. The crops most affected, in decreasing order of importance, were: vegetables, fruits, agronomic crops, lawns, shrubs, woody ornamentals, timber, and commercial flowers. Indirect losses were estimated at $8 million, of which $7 million reflects profit losses, $0.5 million for reforestation of land, and $0.5 million for grower relocation costs. In total, air pollution losses in Pennsylvania for 1969 were estimated at approximately $11 million.

The major criticisms of the effort in Pennsylvania reflect the state-of-the-art. Little is known of the extent to which home garden plantings and flowers are being affected by air pollution; and, if they are affected, at what price they should be valued. The economics of assessing losses is somewhat questionable in that grower profit losses were not included as direct costs, and it was not clear as to what constituted an annual cost and what did not. Also, the translation of physical injury into economic loss is somewhat subjective and has not been standardized.

Lacasse (1971) made an attempt in 1970 to again survey Pennsylvania. In using the same concepts of what constituted a "cost" and what did not as in the previous year's survey, Lacasse estimated direct losses to be $218,630 and indirect losses of $4,000. In explaining the low estimate of losses, Lacasse explains that "...the reason for the lack of widespread air pollution injury to vegatation during the 1970 growing season may have been due to fewer inversions and to no unfavorable growing conditions when air stagnation did occur."[88]

Feliciano - New Jersey, 1971

Similar surveys have also been made in New Jersey and in the New England states. In general, these surveys suffer from many of the same deficiencies as the Pennsylvania survey. Feliciano (1972) reported that losses to agriculture in New Jersey due to air pollution were estimated at $1.19 million in 1971. As in the Pennsylvania surveys, profit losses were not included. A total of 315 reported air pollution incidences were investigated and documented during the period of the New Jersey survey. A "rule of thumb" evaluation method developed by Millecan (1971) was used for estimating losses. As Feliciano describes it, "Where visual inspection of the overall leaf surface of the plants indicated 1 to 5 percent injury, a 1 percent loss was applied for that crop. A leaf surface injury ranging from 6 to 10 percent was given a 2 percent loss; 11 to 15 percent injury, a 4 percent loss; and 16 to 20 percent injury, an 8 percent loss."[89] Estimates of losses were based on the crop value of the acreage affected.

The damaging pollutants listed by decreasing importance were: peroxyacyl nitrates (PAN); hydrochloric acid mist and chlorine gas; ethylene; sulfur dioxide; ammonia; fluoride; and particulates. The first two accounted for 80% of the total incidences reported. Vegetables and field crops experienced about 85% of the total economic loss reported. Damage was reported in 16 of the 21 counties in New Jersey.

Pell - New Jersey, 1972

To obtain a better understanding of the year-to-year variation in plant losses caused by air pollution, Pell (1973) continued the work initiated by Feliciano in 1971. Pell estimated that direct losses of agronomic crops and ornamental plantings for the 1972-73 growing season were approximately $130,000. As in the study by Feliciano, costs associated with crop substitution and yield reductions, were not accounted for. The damaging pollutants, listed by decreasing importance, were: oxidants, 47% of crop losses; hydrogen fluoride, 18%; ethylene, 16%; sulfur dioxide, 4%; and anhydrous ammonia, 1%. Surprisingly, the damage reported in Pell's survey was only 11% of that reported in Feliciano's 1971-72 survey in New Jersey. The significant year-to-year variation is attributed to altered environmental conditions rather than to decreased air pollution concentrations. For example, it is believed that the unusual rainfall patterns in 1972 placed the plants under water stress and thereby protected them from air pollution injury.

Naegele - New England, 1971-72

Naegele, et. al. (1972) reported on a field survey of agricultural losses in the New England region caused by air pollution. Some 83 investigations were made in 40 counties of the six New England states. Direct economic losses for the 1971-72 season were estimated at approximately $1.1 million. Estimates of economic losses were based on grower costs, crop value at the time of harvest, and the possibility of crop recovery following the pollution incident. Here, direct losses also include grower profit losses. It was determined that fruits, vegetables, and agronomic crops suffered the greatest losses, and that over 90% of the damage could be attributed to oxidant air pollution.

Millecan - California, 1970

An approach similar to that used in Pennsylvania, New Jersey, and New England was employed by Millecan (1971) to survey and assess the air pollution damage to California vegetation in 1970. Because of foreknowledge of the distribution of air pollution problems, efforts were concentrated in the Los Angeles Basin, San Joaquin Valley, and the San Francisco Bay Area. Estimates of losses were confined to 15 of the 58 counties in the state. Plant injury from air pollution was observed in 22 counties. Ventura County, with a loss of almost $11 million, experienced the greatest economic crop loss for any one county. Losses of citrus production in the Los Angeles Air Basin accounted for over $19 million of the total monetary loss of almost $26 million. The monetary loss estimate does not include losses attributed to reduction in crop yield or growth except for losses of citrus and grapes. Nor were monetary losses to native vegetation including forests or to landscape plantings estimated.

As expected, photochemical smog accounted for most of the economic losses. Photochemical smog is composed of oxidant-type pollutants like ozone and PAN that are derived from the interaction of nitrogen oxides and hydrocarbons in the presence of sunlight. Analysis of field reports showed that six pollutants accounted for the following percentages of plant injury: ozone, 50%; PAN, 18%; fluorides, 15%; ethylene, 14%; sulfur dioxide, 2%; and particulates, 1%.

Benedict - Nationwide Survey, 1969 and 1971

A major study to estimate plant losses caused by air pollution was undertaken by H. M. Benedict (1971) of Stanford Research Institute (SRI) in 1969. SRI has developed an estimate of the annual economic losses to agriculture in all regions of the United States resulting from damage to vegetation by air pollutants. Special emphasis was placed on those losses ascribable to automotive emissions.

Their work progressed in the following manner: First, counties were selected in the United States were the major air pollutants--oxidants (ozone, PAN, and oxides of nitrogen), sulfur dioxide, and fluorides--were likely to reach plant-damaging concentrations. This selection was based on fuel consumption and the existence of large single-source emitters. Second, relative potential severity classes of the pollution in each county were then estimated, based on emissions area, and potential pollution episode days. Third, crop value estimates were completed for these counties. This necessitated calculating the dollar value of grass hay produced and of pastures. Fourth, estimates of the potential annual value of forests and the annual maintenance costs of ornamental plantings were completed and apportioned by area and population. Fifth, a continuing literature review provided information on the relative sensitivity of different plant species to the selected pollutants, so the percentage loss that might be expected to crops and ornamental plantings in the most severely polluted counties could be determined. Sixth, tables were then prepared showing the percentage loss that might be expected to crops and ornamentals in counties and in the different pollution classes described in the second step above. And seventh, these factors were then applied to the value of the crops, forests, and ornamentals grown in the polluted counties, and the dollar loss value for each crop in each county was recorded. From this, state, regional, and national estimates were obtained.

Thus, dollar loss estimates for agricultural crops and ornamentals were determined using the following equation:

DOLLAR LOSS = (Plant Value) x (Plant Sensitivity) x (Pollution Potential)

When the loss factors for the various pollution intensities in the 551 selected counties were applied to the determined crop and ornamental values, the total annual dollar loss to crops in the United States for 1964, as shown in Table 17, was calculated to be about $85.5 million, and the loss to ornamentals, about $46 million.

The significant weaknesses in the study seem to be: (1) given the paucity of knowledge in the literature on pollutant-yield relationships, many of the damage factors were probably "best guesses" and thus are subject to refinement. The same can be said of the determination of relative sensitivity; (2) the systematic application of factors to determine crop and ornamental plant values, especially the latter, does not allow for individual variation, thus one would expect a great deal of variation in error in any particular county estimate; and (3) ornamentals were under-valued in that only replacement costs were used as a proxy for aesthetic values. Also, the values of recreational areas were not assessed. A major benefit from this study is the accumulation of good background data for the development of more sophisticated predictive models for estimating losses when better data on dose-response becomes available.

Table 17. PLANT LOSSES DUE TO AIR POLLUTION
($ million)

	Oxidants	SO_2	Fluorides	Total
Crops	78	3.3	4.3	85.6
Ornamentals	43	3	0.2	46.2
Total	121	6.3	4.5	131.8

NATIONAL ESTIMATE OF PLANT DAMAGES

The loss estimate of $132 million generated in the SRI study for 1964 is the most defensible of those reviewed. Also, the SRI estimates are consistent with the individual estimates for California, Pennsylvania and elsewhere. Because the SRI study attempted to grapple with losses of ornamentals, the state estimates generated by the predictive model are consistenly higher than those developed through statewide surveys. But even then, the SRI estimate still reflects a lower bound of the true plant-associated losses due to air pollution. This is so because the losses resulting from reduction in yield are largely ignored. Also ignored are costs associated with grower relocation, crop substitution, losses in productivity, and denudation of land and resultant erosion. Due to the lack of adequate knowledge on many aspects of air pollution effects on plants, there are many inadequacies inherent in all reported efforts to estimate plant losses due to air pollution. Although all estimates have their shortcomings, the studies discussed above represent the current state of the art.

By updating the 1964 estimate of $132 million to 1970, the estimated cost of air pollution damage to vegetation is estimated to be approximately $150 million. This is based on the assumption that the same percentage value of crops are lost in 1970 as was lost in 1964.[90] Implicit in this assumption is that the value of ornamental plantings has increased the same as cash crops. By rounding this estimate off to $0.2 billion and then assuming that $0.2 billion is representative of a range, a range of 50 percent or $0.1-0.3 billion will be assumed, with a "best" estimate of $0.2 billion for 1970.[91]

SECTION VIII
ASSESSMENT OF THE EFFECTS ON AIR POLLUTION ON AESTHETIC PROPERTIES

OVERVIEW OF THE PROBLEM

This very nondescript receptor category is concerned mostly with the organoleptic aspects of air pollution--those pertaining to sight and smell. Given the level of public esposure, it can be considered public knowledge that air pollution restrains progress toward an environment congenial to aesthetic and other socially conditioned needs. Peckham's[92] review of the literature has provided a good starting place in understanding the seriousness of this aspect of the air pollution problem.

One possible effect of air pollution is the deterioration of materials with historic or artistic significance, such as paintings, statuary, and rare books. Air pollution that reduces visibility and obscures vistas can also have a depressing psychological effect on individuals. Noxious odors represent another series of effects that are considered here to be aesthetic effects of air pollution.

Aesthetic effects also belong to the calculus of pollution damages because of values that could be attached to prevention or avoidance. For example, the New York City Public Library spent $900,000 between 1952 and 1967 to microfilm books that were in an advanced state of deterioration due significantly to air pollution.[93] Part of this expenditure represents what the library was willing to pay to avoid book losses from air pollution.

In general, man wants an environment congenial to his aesthetic and phychological needs. Yet air pollution restrains progress toward such an environment. Odors from various industrial sources deprive many of the full enjoyment of their property. Particulates dangerously diminish visibility. Oxides of sulfur accelerate the decay of honored works of art and statuary. Emissions from automotive combustion and their resultant atmospheric interactions injure the trees that adorn our urban arteries and often cause watering of eyes, thereby diminishing our quality of life.

ODORS

Odors have historically generated a high level of public concern. This is clear from opinion surveys. For example, in the St. Louis survey,[94] 926 out of 1361 complaints received during the 1958-1962 period pertained to odors. In an opinion survey taken in Clarkston, Washington,[95] 91% of the respondents made a similar identification of air pollution with odors.

Regardless of the area they cover, odors can deprive people of the full use and enjoyment of their property. A survey of the court records might be a good way to determine the seriousness of this deprivation. For example, 31 homeowners brought suit against the Weyerhauser Company to recover damages caused by odors emitted from the company's kraft pulp mill in Elkton, Maryland.[96] The testimony was convincing enough in that the court awarded the plaintiffs the amount of about $18,000. In another case, plaintiffs were awarded over $35,000 as a result of a suit filed against an industrial concern for emanating odorous pollutants that resulted in hospitalization costs, loss in earning, and the loss of enjoyment of their properties.[97] Other similar judgments are extensively recorded in the legal records. Yet some decisions from recent cases seem to indicate that the rights of individuals to odor-free air have not been well established. For example, a recent ruling by the United States District Court in Cincinnati ruled that odors from a dump site are not illegal.[98] A suit had been brought by 22 property owners who complained that odors from the disposal site fouled their air and deprived them of their rights to clean air and the free use of their property. The judge ruled that the United States Constitution does not guarantee citizens the right of protection of their environment. A similar ruling was made in a Michigan court case where the plaintiff claimed that hog odors from a neighbor's farm had an "adverse effect" on her sick husband.[99]

Not surprisingly, the major obstacle to initiating action against odor problems begins with measurement. As reported by Dravnieks, "Odor dimensions are intensity, detectability, acceptability, and quality (character). Human response to odors is not linearly related to the concentrations of odorants in air and relates to the chemistry of odorants in a complex way. The response is influenced by criteria which the individuals use to interpret odor sensations and by the form of response expected or accessible, especially in community setting."[100] Methods for evaluating odor problems have been developed by Copley International Corporation.[101] These are to be field tested in selected metropolitan areas throughout the country. Copley found that people were generally unaware of any adverse economic effects of odors pollution, or they did not believe such effects existed.[102] It is likely that people are generally unwilling to admit these kinds of effects do exist.

VISIBILITY

Air pollution not only affects the olfactory senses but also the sense of sight. Serious hazards to transportation are created by visibility-reducing air pollutants; they cloud the landscape with haze and smog and discolor the sky. The visibility-restricting air pollutants are particulates and nitrogen dioxide.

Particulates in the atmosphere can affect visibility in two ways--either by absorption or by scattering of light. The nature and magnitude of the effect are functions of the chemical composition of the particle, particulate size, shape, and concentration. Particulates also exert an indirect effect upon visibility by facilitating the formation of fogs and by slowing their dissipation, making travel difficult and hazardous.

Poor visibility can also result in accidents and disruptions in transportation. It has been estimated that adverse effects of air pollution on air travel cost from $40 to $80 million annually.[103] The Civil Aeronautics Board, in reviewing 1962 aircraft accidents in the United States, found at least six to be directly due to what they called "obstruction to vision" caused by smoke, haze, dust, and sand.[104] Delays in the movement of air traffic are quite common at major commercial airports during times of poor visibility.

As Peckham has said, "People want safe and dependable transport. They want to be able to travel without extraordinary risk or delay. Furthermore, most people also want access to pleasing scenery and bright, clear weather with sunshine. Air pollution can often defeat these wants by depressing visibility, blocking sunshine, and intensifying fog. This seems clear from the evidence. What is not so clear, however, is the monetary magnitude of the injuries suffered."[105]

Vars and Sorenson (1972) attempted to measure externalities associated with the visibility-reducing air pollution generated by open field burning in Oregon's Willamette Valley. Utilizing a market study approach, they constructed a theoretical model to explain the relationship between air quality and consumer behavior, or more specifically, the consumption of recreation-related activities. The consumer was viewed in the model as literally producing consumption activities by combining market commodities and time in different combinations so as to create an activity he then consumes. While the theory was straightforward, albeit complex, it was not amenable to empirical analysis. There was not only the problem of the lack of a priori information about the comsumption activity production functions, but also a second difficulty arising from the lack of a priori information on what activities would be affected negatively by a deterioration in air quality and which activities would be affected positively, as they perform the role of substitutes.

These empirical problems led to a redesign in research plan. The subsequent investigation employed multiple regression analysis in examining the determinants of the following recreation activities: (1) swimming pool use; (2) golf course attendance; (3) number of visitors at the state Capitol; and (4) the number of overnight campers at a selected state park. By hypothesis, participation in these activities should be affected by, among other things, air quality. It was predicted that all but the number of visitors at the state Capitol would be negatively affected by a worsening in air quality. Attendance or use was treated as the dependent variable, while the independent variables included minimum daylight visibility, high temperature, and day of the week. Data recorded between July 15 and September 30, 1970 on the participation in these activities were analyzed.

The results showed no significant relationships between rounds of golf, indoor swimming pool attendance in Eugene, Oregon, and minimum visibility. On the other hand, the hypothesized relationships between minimum visibility and attendance at outdoor swimming pools in both cities were positive. Statistically, the relationships were significantly different from zero at the 95 and 99% levels of significance. Overall, the hypothesis that air quality affects the extent to which individuals undertake (consume) outdoor recreational activities, was supported. In addition, the evidence supports the hypothesis that consumers, in fact, do engage in activity substitution under variations in air quality.

Sorenson's data on swimming pool attendance as calculated over the range of minimum visibilities in Eugene and Salen, imply that a 20% improvement in visibility associated with a ban on open field burning would increase the number of swim-days for residents by 60,000 to 90,000. Valued at an admission fee of $0.50, the value of this increase in swim-days amounts to a sum of $30,000 to $45,000. By assuming an elasticity of aggregate resident recreational activity with respect to daylight visibility of 0.1, and extrapolating to the entire Willamette Valley, estimates of increased recreational experiences are generated. Economic values were based on the range of values suggested by the Water Resources Council for the evaluation of outdoor recreation days.[106] Vars and Sorenson determined best estimates of the value of increases in Willamette Valley resident outdoor recreation activity, consequent to the three policies under investigation, to be: (1) $249,000 for a ban on open burning; (2) $111,000 for a policy allowing alternate year open burning, and (3) $160,000 for a policy allowing open burning once in three years.[107]

The second portion of the empirical research design consisted of a statistical analysis of data derived from interviewing 401 tourists travelling in Oregon during periods of reduced air quality. It was hoped that information on tourist perceptions and response to reduced visual range, could be secured. Yet, again, the lack of a priori information about the consumer activities production functions complicated the empirical problem. This sample population was divided into polluted and non-polluted areas, based on the hypothesis that recreation activities in the "clean" area would be substitutes for recreation activities in the "dirty" area because of the adverse aesthetic effects of poorer air quality. One particularly interesting aspect of this was the investigation of whether tourists were sufficiently "tracked" in their behavior or whether they were flexible to the extent that their plans were causually subject to change.

Data showed that of the 59 respondents who indicated that their plans had changed upon entering the state, only six associated that change with air pollution. Further analysis showed that tourists have fairly fixed plans about the path of their travels and the amount they will spend. Quite obviously these six responses cannot be viewed as statistically significant in relation to any of the hypotheses about behavior or perceptions of interest to this study.

Vars and Sorenson concluded that in terms of the hypothesis about the effects of air pollution that this research set out to examine, the findings must be viewed as negative. It is possible that the experience of most Americans has suggested that air pollution is more or less pervasive, and that they select among available recreational activities as if air quality were constant.[108] In an indirect criticism of the market approach, Vars and Sorenson observe that it will be very difficult for social scientists to observe a clearly defined relationship between air pollution and the behavior of people, even though the behavior of people would be related implicitly to air pollution.

WORKS OF ART

Another kind of injury to aesthetic sensitivities occurs when air pollution accelerates the decay of stonework. Calcarous materials such as limestone, marble, lime plaster walls, and frescoes are subject to chemical assault by acids which are formed by the interaction of sulphur and nitrogen oxides and moisture. One such example of international significance is the damage that has occurred to the 14th century Giotto frescoes in the Scovegni Chapel at Padua, Italy. These frescoes have been the object of special studies. By late 1960, these works had experienced severe deterioration and scaling of paint.[109]

The assualt of atmospheric pollutants on antiquities, metal, and stone artwork occurs all over the industrial world. In New York City, air pollution has contributed to the spoiling of the facade of City Hall, resulting in a $4 million expenditure for restoration.[110] And, officials of the Metropolitan Museum of Art have been forced to coat statuary with beeswax and to air condition exhibition areas. The Operating Administrator has explicitly stated: "The presence of various forms of sulphur in the air is particularly injurious to limestone and marble. There is an appreciable, visible etching on marble... I would say that all of the exposed stonework of ancient elements at the Cloisters has deteriorated since its erection in New York City...It is pointless to collect outstanding works of art, many over a thousand years of age, if one thousand years from now they are going to be so badly deteriorated as to be virtually worthless."[111]

In Spain, several Titians, Rubens, and other priceless works of the Italian, Flemish, and Dutch schools are reportedly in danger of serious damage due to the polluted air in the Prado Museum. Although experts have warned for 12 years that air pollution in Madrid was damaging the valuable canvasses, the Spanish government only recently ordered emergency measures to protect the 3,000 major paintings that are housed in the former palace.[112] As a result of these kinds of dangers, it is hoped that preservatives can be applied to help retard decay in marble and limestone.[113]

ORNAMENTAL PLANTINGS

Another category of effects that should rightfully be classified as aesthetic include the destruction by air pollution of ornamental flowers, shrubs, and trees that normally provide some sense of aesthetic enjoyment. These could be ornamental flowers and shrubs that surround our homes, trees that line our traffic arteries, or trees and other vegetation that normally grow in parks and other areas used for purposes of recreation. Heggestad has reported phytotoxic effects of common urban pollutants on lilacs, petunia, orcnid, and gladioli.[114] Also, it has been reported that some 160,000 acres of ponderosa and jeffrey pine in Southern California are experiencing severe decline, and this has been attributed to the oxidant air pollution generated in the Los Angeles Basin.[115] This is significant in that a large part of the natural ecosystem is being affected, and this area is one of very high recreational value.

CONCLUSIONS

As Ayres has summarized, "The disutility arising from minor discomfort and essentially aesthetic objections to air pollution is probably the most underestimated and certainly the fastest-growing component of the total problem. This arises from two interrelated factors: (1) the rising level of education on the part of the population and even more rapid rate of increase in the means and possibilities of communications, all of which results in an explosive increase in the level of awareness and general perception of the pollution problem as compared with a few decades ago, and (2) the fact that comfort and aesthetic satisfaction are 'superior goods', as many economists have pointed out, and the demand for them grows nonlinearly with general prosperity and affluence, which are themselves rapidly increasing."[116]

Given that the aesthetic qualities of our environment do have some economic dimension, we are faced with the problem of measurement in quantifiable economic terms. S. V. Ciriacy-Wantrup makes a strong case for the use of the terminology, "extra-market" rather than "intangible" to describe those benefits that are not routinely valued in the market place. Further, he argues that attempts to quantify such values should be encouraged, and indeed, if the measurement of air pollution damages is to be realistic, these extra-market values must be assessed.[117] The SRI vegetation study estimated the value of ornamental plantings. Copley International Corporation (1971) made an attempt to estimate odor costs by analyzing property value differentials. Vars and Sorenson (1972) made an attempt to estimate the impact and value of air pollution as it affected recreation-related activities in Oregon. While none of these studies has been particularly successful in identifying the pollution exposure-receptor response relationship, progress is being made in understanding the value of social choices that man explicitly and implicitly makes every day. The major difficulty lies in isolating the incremental effect of changing air quality on man's aesthetic and psychological needs. Even though measurement is difficult, it is quite obvious that society is willing to expend significant resources to reduce aesthetic damages from pollution.

SECTION IX
ASSESSMENT OF THE EFFECTS OF SOILING

OVERVIEW OF THE PROBLEM

Individuals, households, and commercial establishments are affected by air pollution in many ways, only a few of which are obvious. When dust particles fall, the need to dust window sills and furniture is distressingly obvious. But the effects of air pollution in most cases are so much more gradual as to be unnoticed. Yet the costs of dealing with these effects may involve considerable extra expense of which the household is usually unaware. In urban areas some families spend very little as a result of air pollution, but many spend hundreds of dollars more each year than they would need to if the air were clean.

INDIVIDUAL STUDIES

Mellon Institute - Pittsburgh Nuisance

The best known of the early studies of economic losses due to air pollution is the Mellon Institute Study of the Pittsburgh smoke nuisance reported by O'Connor (1913). The purpose of the study was to assess the economic cost of the smoke nuisance to the populace in the city of Pittsburgh. The cost estimates were based upon literature searches, observations, and informal surveys. The damage estimates obviously included some direct costs as well as some adjustment costs. The costs reflect losses due to soiling, corrosion, and the obstruction of sunlight by particulates. Questionable statistical techniques were used in averaging damage costs, in estimating the number of units (i.e., stores) affected, and in arriving at the percentage damage due to air pollution.

Beaver Report - London Smog Episode

The next major attempt to estimate soiling costs was an outgrowth of the Mellon study. As a result of the London "smog" episode in 1952, a committee was appointed in 1953 to examine the nature, causes, and effects of air pollution and the efficacy of preventive measures. The report to Parliament was released by Hugh Beaver (1954).

Much of the data were secured through literature searches and informal surveys. The actual method used to make the estimates was similar to that used in the Mellon study. In the Beaver Report, however, "black" areas were compared with "clean" areas, whereas in the Mellon study, Pittsburgh was compared with different cities. Costs were assessed in the Beaver study by estimating the proportion of the total expenditure on a specific item that is attributable to air pollution. The necessary proportional estimates were obtained from additional estimates of the amount and frequency of expenditures in polluted versus non-polluted areas, as determined by interviews with local authorities. The polluted areas in the study were assumed to contain one-half of the total population as thus one-half of all other items, i.e., painting of buildings, etc.

It is evident that this method resulted in extremely crude lump sum figures with only simple correlation with pollutant level. Where little or no information was available, the investigators did not hesitate to use pure guesswork. It should be noted that the investigator recognized that his results did little more than suggest a broad order of magnitude.

Michelson and Tourin - Household Costs

In recent years, several attempts have been made to identify the costs of soiling due to air pollution. For the most part, these studies have worked with the household as the primary unit of investigation in an attempt to measure pollution-related cleaning and maintenance costs.

In the area of evaluating household costs of soiling, the work of Irving Michelson has received the most attention.[118] Michelson's method of study is based upon the hypothesis that if air pollution causes meaningful soiling, the intensity of soiling should be reflected in a shorter time interval between successive cleaning and maintenance operations in areas with higher levels of pollution. If the relationship between particulate level and the frequency of cleaning and/or maintenance operations could be established, soiling costs could be calculated by applying a cost factor for each operation studied.

To test this theory, Michelson and Tourin (1966) conducted a survey by mailed questionnaire in the towns of Steubenville and Uniontown in the Upper Ohio River Valley. These towns have annual average particulate levels of 235 $\mu g/m^3$ and 115 $\mu g/m^3$, respectively. A high response rate was achieved through a large publicity campaign, and a positive relationship was found to exist between the cleaning frequency of the home and of personal care items and the particulate level.

Cost comparisons were made within two income groups (less than $8000 and more than $8,000), and the total costs were calculated on the basis of the number of families and persons in each income group in each city. The differences in frequencies were calculated and then converted into dollar differences by applying local market prices for the various household services used in the survey. The resulting figures showed that the economic cost of air pollution for Steubenville was $3.1 million, or $84 per capita higher than in Uniontown.

In an attempt to validate this study, a subsequent survey by Michelson and Tourin (1967) was conducted in three suburban cities of the Washington, D.C. area. The Washington area was chosen for the validating study because it was thought to offer a severe test to the method. First, the absolute levels of suspended particulate in the D.C. area were very much lower. Second, the difference in the levels of suspended particulates of the paired cities was so much smaller in the Washington area as compared to the paired cities of the Upper Ohio River Valley. Finally, the character of the two areas was very different as far as industrial mix and population characteristics.

Again, Michelson found a positive relationship between the frequency of cleaning and maintenance operations and the level of suspended particulates. Although the findings of the Washington, D.C. study would seem to support the findings of the Ohio study, there appear to be not only major differences between the two studies but also inherent problems within each that throw some doubt upon his conclusion. For example, income level was the only controlling factor in the analysis. Furthermore, only the responses of the above-average income group were analyzed in the Washington study. Once the relationship was found to exist in that income group, it was assumed to exist for the below-average group in his estimate of total and per capita soiling costs. In summary, the principal weakness was the lack of statistically reliable techniques.

Since these two major studies, Michelson and Tourin (1968) have applied their method of estimating the total extra household costs resulting from air pollution in Connecticut. In this study, no household survey was performed to measure the frequency of cleaning and maintenance operations. Instead, the frequencies were taken from the Upper Ohio River Valley and Washington, D.C. area studies. Because these frequencies were not alike, some kind of "averaging" was done. The local costs of the operations were investigated, and the demographic figures from census materials were used to arrive at a total damage estimate for the state of Connecticut. The usefulness of this method without adequate verification is questionable.

Ridker - Urban Soiling

Ronald Ridker also did research in identifying the soiling costs of air pollution.[119] In 1965, Ridker conducted a study in high, medium, and low pollution zones of Philadelphia to determine whether family behavior and expenditures were affected by air pollution. Despite the apparently adequate collection of data, the results of the analysis were inconclusive. Although there appeared to be some detailed problems and errors in the analysis, the principal problem involved the use of time spent in routine household cleaning, which may very well be an inappropriate estimate of these costs. The relative frequency with which these tasks are performed may be a more appropriate measure.

Ridker also conducted a time-series analysis of a pollution episode in Syracuse.[120] A questionnaire was developed and administered by personal interview. Although the results of this household survey were much better than the cross-sectional analysis in Philadelphia, the approach was obviously limited to the episode-type situation and could not be put to widespread use.

The Michelson and Ridker soiling studies have indicated several major problem areas with regard to evaluating household soiling costs due to air pollution:

1. Isolation of costs due to air pollution from those due to other variables.
2. Sample selection and bias.
3. Development of a survey technique that will provide reliable answers.
4. Inclusion of all household tasks whose costs are influenced by soiling damage from air pollution.

Booz, Allen and Hamilton - Phildelphia Survey

The Booz, Allen and Hamilton, Inc. (1970) residential soiling study in Philadelphia was expected to improve upon and extend the methodologies already developed. A questionnaire consisting of two sections was developed to determine the frequency of cleaning. The first section included questions regarding cleaning operations and the second consisted of a set of self-referent statements designed to determine cleaning attitudes. A total of 1800 personal interviews were conducted in the Philadelphia region.

Booz-Allen employed rigorous statistical survey techniques from the outset of the project. These techniques were employed because of the belief that other, perhaps more dominant, non-pollution variables explain differences in the frequencies of many residential cleaning and maintenance operations to a far greater degree than the variations in the annual air particulate levels. Therefore, the survey techniques included: (1) a probability sample within several zones of the Philadelphia area; (2) group-depth interviews leading to pre-estimates of attitudes toward cleaning and the best ways of phrasing survey questions; (3) personally administered questionnaires, rather than mail or telephone surveys; (4) a factor analysis of the questionnaire respondents to separate the population into attitude groups in order to better explain why people clean; (5) collection of demographic data on each respondent and his residence; and (6) the use of qualified interviews coding, and keypunching operations.

The study of residential household soiling costs made an attempt to discern between cleaning necessitated by pollution and cleaning by habit or other factors. Before any relationship could be established between the frequency of these cleaning operations and the level of particulate pollution, other socioeconomic variables that may contribute to the frequency were identified and the degree of their interaction established through a factor analysis.

From the study of 27 cleaning and maintenance operations, results indicated that the range of annual air particulate levels experienced in the Philadelphia area (approximately 50 to 150 $\mu g/m^3$) had no statistically significant differential effect on the residential cleaning and maintenance costs for over 1,500,000 households in the area. These operations included painting, cleaning, and washing. Of the 27 operations shown in Table 18, 11 were determined to be somewhat sensitive to air particulate levels. Each of the sensitive operations is a low-cost, do-it-yourself item, and many are associated with being able to see out of the house--washing windows, cleaning screens, and cleaning venetian blinds. It must be pointed out that these do-it-yourself operations were considered to be free of labor cost. The material costs of these do-it-yourself operations were considered only when such costs were considered to be non-trivial, such as the cost of painting.

They concluded that some low-cost cleaning and maintenance operations appear to be sensitive to air particulate levels, but more importantly, the high cost operations are unaffected by variations in air particulate levels in the Philadelphia area. Another finding of interest indicated that a higher proportion of residents of high-pollution areas believed their neighborhoods were dirtier than did residents of low-pollution areas.

On a smaller scale, an attempt was made to determine the costs of soiling borne by commercial establishments because of particulate pollution. A sample survey of 138 stores was conducted and various cleaning operations were investigated. Because of the poor return in the sample, the results have proved inconclusive. Also, because of contractual arrangements, cleaning functions are performed at the stores at regular intervals, whether "needed" or not.

Table 18. RELATIONSHIP OF CLEANING AND MAINTENANCE OPERATIONS TO AIR PARTICULATE LEVELS

	Relationship	
	Sensitive	Insensitive
Inside		
Clean and oil air conditioners		x
Clean furnace		x
Clean venetian blinds and shades	x	
Dry-clean carpeting		x
Dry-clean draperies		x
Paint walls and ceilings		x
Replace air conditioner filter	x	
Replace furnace filter		x
Shampoo carpeting		x
Shampoo furniture		x
Wallpaper walls		x
Wash floor surfaces	x	
Wash walls		x
Wash windows (inside)	x	
Wax floor surfaces	x	
Outside		
Clean and repair awnings		x
Clean and repair screens	x	
Clean and repair storm windows	x	
Clean gutters	x	
Clean outdoor furniture	x	
Maintain driveways and walks	x	
Maintain shrubs, flowers, etc.		x
Paint outside trim		x
Paint outside walls		x
Wash automobiles		x
Wash windows	x	
Wax automobiles		x

The data collected in the Booz-Allen study are extensive, but the analysis performed was of a very limited nature. Some of the conclusions are believed to be unwarranted. For example, great care was taken to collect demographic and social motivation data because these variables were assumed to be perhaps more important than the air pollution variable. Yet, the analysis of these data shows that no more than one variable was considered in the attempts to identify the soiling damage functions. In all likelihood, the within-zone variability of these factors would so increase the maintenance frequency scatter that it would be impossible to see any statistically significant effects of pollution levels. It is this author's opinion that such is the case with the activity of painting ouside walls. Booz-Allen concluded that this activity was not sensitive to differences in particulate levels because the frequencies between zones were not statistically significant. These data warrant further analysis to account for some of the confounding factors considered.

The Booz-Allen report has been criticized on several grounds: (1) statements concerning the statistical significance of operations have not been adequately justified in many instances; (2) the sensitivity or insensitivity of the cleaning and maintenance operations is not fully explained; and (3) accepted economic principles justify including with the cost of materials some imputed values for homemakers' time spent in cleaning and maintenance operations.

CONCLUSIONS

In conclusion, the Michelson, Ridker, and Booz-Allen studies dealt mainly with the estimation of household cleaning and maintenance costs. Except for Michelson, the evidence to date indicates air pollution does not have significant economic effects in terms of household maintenance and cleaning operations. A cost estimate will not be derived for this category in this report because: (1) the Michelson estimates do not appear to be acceptable for the purpose of extrapolation; and (2) those soiling costs associated with painting have already been estimated by Spence and Haynie (1972).

Yet, intuitively, other than what is implicitly measured in property value differentials, it is difficult to conclude that there are not significant soiling-related costs. Some of the significant costs that perhaps deserve attention include: commercial cleaning and maintenance costs; individual adjustments such as laundering, dry cleaning, and hair and facial care; car washing; and costs to quasipublic properties, which might include cleaning and maintenance costs of buildings and monuments and washing of street luminaries. The magnitude of soiling costs associated with specific effects undoubtedly runs into the millions of dollars annually, but because of the lack of data, these soiling costs will not be estimated in this report.

SECTION X

EFFECTS OF AIR POLLUTION ON ANIMALS

OVERVIEW OF THE PROBLEM

Generaly speaking, air pollutants enter the bodies of domestic animals and wildlife via inhalation or ingestion of contaminated vegetation. Lillie[121] and Stokinger and Coffin[122] provide good reviews of the effects of air pollution on animal organisms. Fluorine by-products, lead, and arsenic are the major offending constituents in industrial pollution. Dusts, ammonia, hydrogen sulfide, and sulfur and nitrogen oxides cause less of a problem. Pollution of agricultural origin is oftentimes linked to the misuse of pesticides. Urban air pollution has been implicated as a causal factor in the poor health of zoo animals. While no empirical studies to estimate air pollution damages to animals have been attempted, a brief survey of the literature will, hopefully, place this problem in perspective.

DOMESTIC ANIMALS

Some of the odlest documented cases of the deleterious effects of air pollution have been associated with the Meuse Valley disasters, notably in 1897, 1902, and 1911. Vegetation and cattle were known to suffer from adverse atmospheric conditions, locally called "fog disease."[123] In actuality, the cattle had been stricken with asthma and emphysema.[124] An analysis of data collected in Donora, Pennsylvania, has shown that a positive correlation exists between the smog and the health of small domestic animals--dogs, cats, poultry, and rabbits.[125]

Fluoride poisoning of cattle grazing in the vicinities of aluminum reduction and phosphate fertilizer plants has demanded much attention in the literature. Fluorosis, a disease common to cattle, occurs when fluorine compounds are ingested for long periods of time. The animals eat contaminated fodder, grass, and hay, and also inhale quantities of fluorine. Chronic fluorosis is typified by severe dental malformations and bone lesions. Acute fluorosis often results in stiffness, anorexia, weakness, convulsions, and cardiac failure.[126] Cattle with fluorosis often show a reduction in milk production and conceive poorly.[127] Middleton[128] reported that registered steers in Polk County, Florida, once valued at $3,000 a head, were sold for as little as $50 or were slaughtered because they were crippled and made helpless by eating fluoride-poisoned grass.

Losses to livestock have been known to occur in the vicinity of lead smelters and refineries.[129] Molybdenum dust, scattered from the chimney of the neighboring molybdenum-smelting factory, also has allegedly caused damage to livestock. The cattle developed diarrhea and malnutrition. Also, decreases in production and in the rate of conception were found.[130] Animals also have been damaged by the effluents of a copper smelter. The high copper and arsenic output that deposited on plants and grass caused numerous cases of poisoning and even the death of domestic animals such as cattle, horses, sheep and poultry.[131]

WILDLIFE

A number of general conclusions have been drawn regarding air pollution effects on wildlife. From field investigations, the economic poisons--insecticides, herbicides, chlorinated hydrocarbons, organic phosphates, etc.--appear to outweigh by far all other types of air pollutants as hazards to wildlife. Wildlife is chiefly affected by ingestion of the "fallout" of the air pollutant.

The relative susceptibility of various species to specific air pollutants is far from clear, but it would appear that the mammals are considerably more susceptible than birds.[132] Yet air pollution has been implicated as the causal agent of primary lung cancer in birds in the Philadelphia zoo. Synder[133] has focused attention on the possibility that the amount of carcinogens in the atmosphere is increasing, because water fowl that were kept outdoors the year round were those animals most affected. It has also been reported that lead poisoning of zoo animals has become a significant problem at the Staten Island Zoo. The major source of the lead appears to come from atmospheric contamination.[134]

CONCLUSIONS

The damage to animals caused by air pollution has generally been localized and its economic consequence has probably been relatively unimportant; but the social consequences of this pollution are potentially more severe. Though indirect, the risk to the food cycle, especially when pesticides are implicated, could be serious; and it may be true that the economic importance of heavy metals and other toxic substances may lie in their impact on animals. In general, little is known about the effects of urban air pollutants on domestic animals and zoo animals. The pollutant burden in these animals might offer an area of fruitful research.

Tolerance limits, much less damage functions, have not been developed for domestic animals exposed to air pollutants except for fluoride with cattle, swine, and poultry, and ammonia and carbon monoxide with poultry. In general, air pollution does not appear to constitute a major potential health hazard to domestic animals. However, the cadmium content of milk throughout the United States has revealed levels higher than safe limits.[135] This finding, coupled with evidence that other edible tissues of animals show increasing concentrations of air toxicants, indicates the importance of the potential impact that air pollution could have on the food chain.

SECTION XI

EFFECTS OF AIR POLLUTION ON THE NATURAL ENVIRONMENT

OVERVIEW OF THE PROBLEM

The general effects of air pollution on the natural environment or biosphere, have yet to be clearly delineated, let alone evaluated in economic terms. Nevertheless, it is useful to mention some of the more pronounced effects that air pollution may have, thereby providing a perspective of economic dimension. The impacts of air pollution on the natural order of things are important because again, we are dealing with the problem of scarcity--the scarcity of natural resources.

Damage studies typically examine specific types of pollution effects and attempt to isolate the damages of air pollution on a very limited basis. However, the effects and damages associated with air pollution are likely to have repurcussions beyond the simple effect investigated. Thus, there is a need to trace out the interdependent effects of air pollution, and it is this broader approach that recognizes the effects of air pollution as inherently related to other aspects of man's activities and his natural environment. Such a study is relevant, because it forces an examination of the global and other less quantifiable aspects of air pollution effects. Increasingly, air pollution is being considered a global problem not because of its individually minor effects, but because of its collectively major effects.

When we talk about the natural environment or ecology, we are concerned with the relation of living things to their environment and to each other. Over time, the environment is altered, naturally and by man. The so-called ecological balance, then, is a transitory, everchanging state of relationships of living things to each other and to their environment. We can conclude, then, that it is not conceivable that there is, ever has been, or ever will be, an ideal, all-inclusive ecological balance.[136] The economist, then, is interested in what way major perturbations of this changing ecological balance impact upon man and his welfare.

Environmental problems normally arise because the natural assimilative capacity of the environment is exceeded. Bower and Spofford state, "The natural environment has a capacity to assimilate, in some degree, all forms and types of residuals through the mechanisms of transport, transformation, and storage. In effect, the environment acts as a buffer between the discharger and the receptor, that is, it dissipates, absorbs, dilutes, and degrades or modifies residuals. However, the capacity of the environment to assimilate residuals varies from place to place and from time to time, depending both upon local conditions and upon the stochastic nature of some component of the environment, such as stream flow, temperature, and sunlight."[137]

Actually, little is known about the ultimate fate of pollutants once they are emitted into the atmosphere. Some of the pollution undoubtedly moves into the upper atmosphere where it can remain for long periods of time, but most is probably washed out. The continual deposition of pollution on the earth's surface may be creating irreversible imbalances by affecting the nutritional content of the soil as well as the delicate balance of soil microbes and other organisms important in food chains.[138] When we examine the details of food cycles, we see that the living and nonliving elements in nature are found together in the ecosystem through which energy cascades and matter cycles.[139]

Intuitively, scientists feel that air pollution should have some bio-climatic effects. Will the discharge of CO_2 and heat into the atmosphere create the infamous "greenhouse effect" and cause the polar ice caps to melt, or does the slight increase in the earth's temperatures indicate that the discharge of particulates into the atmosphere causes a reflection of solar rays resulting in cooler temperatures? Indeed, little is known about the impact of man's activities on the geophysical and biological world.

Aspects of global ecology enter also into the accumulation of toxic substances. Woodwell[140] argues that there are global, long-term ecological processes that concentrate toxic substances, sometimes hundreds of thousands of times, above levels in the environment. These processes include not only patterns of air and water circulation, but also a complex series of biological mechanisms. Over the past decade, detailed studies of the distribution of both radioactive debris and pesticides have revealed patterns that have surprised even biologists long familiar with the unpredictability of nature. Yet as Moriarity points out, there is little evidence to suggest that pollutants do concentrate along the food chain.[141]

Climatic effects have also been associated with air pollution. Scientists have shown measurable and distinct differences between the climate in the city and that in its environs.[142] Air pollution is recognized as a significant causal factor. In the city, temperature and humidity are generally higher, precipitation and cloud cover are more frequent, and fog is more common. In extrapolating such findings, we should obviously be concerned with any major changes in the global climate. Weather has a tremendous effect on many animal populations. If an entire area warms or cools significantly, the reproduction, growth, and survival of organisms in that area could be affected.[143] It has been reported that in the Northeastern United States, rainfall shows higher acid content than heretofore.[144] This has been blamed by scientists on air pollution. Oxides of sulfur and nitrogen are believed to be converting to strong acids, thus, increasing rainfall acidity 10 to 100 times. Some fear has been expressed that this could prove to be a water supply contaminant. Sweden is experiencing a similar problem, and Brohult has concluded that the acid rain is leaching nutrients that are essential for forest growth from the forest soils.[145]

CONCLUSIONS

There is much to learn about the effects of pollution as it intervenes into the life processes of the food web, productivity, populations, distributions, and the mechanisms of reinoculation. As Porter argues, "As we lengthen and elaborate the chain of technology that intervenes between us and the natural world, we forget that we become steadily more vulnerable to even the slightest failure to that chain."[146] Many of these consequences of air pollution are not without some economic value. While macro-economic analysis might be premature in many areas where the human and natural ecological relationships are not clearly defined, micro-economic analysis can aid in the identification of those possibilities that are economically feasible, resulting in a more efficient allocation of research efforts.

Even though the effects of pollution on ecological systems are not known, nor the probability of catastrophic events, it is obvious that people are concerned and are willing to spend money to reduce these effects and probabilities. The amount people are willing to pay to avoid ecological risk is probably very large in the aggregate and should be included in any estimate of the benefits to society from reducing pollution. However, given the paucity of such information, no numbers are currently available.

SECTION XII
ESTIMATION AND ALLOCATION OF NATIONAL GROSS DAMAGES

GROSS DAMAGE ESTIMATION

Methods and studies have been examined in this report to determine the economic value of the damages of air pollution. It is concluded from this review of the six measurement methods that can be used to estimate costs of pollution, only two have been used successfully in developing defensible damage estimates--the market study approach employing the property value method and the technical coefficients approach.

The property value method provides a national estimate of air pollution damages ranging from $3.4 to $8.4 billion with a "best" estimate of $5.9 billion for 1970. Anderson and Crocker argue that the property value estimate can, with great confidence, be considered a lower bound of the economic value of the negative effects of air pollution. As argued earlier in this report, it is assumed here that property value, or site value differentials measure primarily aesthetic and soiling costs.

Studies of the costs of air pollution associated with human health, materials and vegetation were also reviewed. These studies have used the technical coefficients approach. The damages from air pollution determined in this manner sum to $3.0 to $11.0 billion, with a "best" estimate of $7.0 billion. These national damage estimates for 1970 are summarized in Table 19. Estimates were not generated in this report for the other effects--animals and environmental risk--because of data limitations.

The problem now is to try to understand how the estimates of $5.9 billion and $7.0 billion relate to each other. The best that can be done is to make intelligent, intuitive interpretations. The components of the latter cost estimate have been fairly well defined; the former, much less so. In theory, the housing market estimator should capitalize all of the economic costs associated with polluted air. In the real world, however, this is unlikely because the property market is less than perfect. This is because some losses are probably capitalized in durable resources that are immobile, and some of the effects are perhaps so insidious as to go unnoticed by consumers.

Table 19. NATIONAL ESTIMATES OF AIR POLLUTION DAMAGES (UNADJUSTED) 1970. ($ billion)

Effect	Range of Damages		
	Low	High	"Best" Estimate
Aesthetics and soiling[a]	3.4	8.4	5.9
Human Health[b]	1.6	7.6	4.6
Materials	1.3	3.1	2.2
Vegetation	0.1	0.3	0.2

[a] Property value estimator

[b] Does not include estimates of losses attributable to oxidant-related air pollutants because of data limitations.

Thus, what does the property value differential estimate? As discussed earlier, many authors agree that what are probably implicitly contained in this estimator are the aesthetic aspects of air pollution--costs associated with soiling, odors, visibility-restriction, "psychic" effects, and losses of plant ornamentals. If such is indeed true, then it would seem justifiable to add the property value differential estimate to the $7.0 billion estimate which is the sum of losses that, in general, do not significantly overlap with those losses capitalized in the residential property market. This would sum to a total of $12.9 billion.

At a minimum, there would be two areas of overlap: (1) the value of plant ornamental losses as estimated in the study by Benedict (1971). Yet even here this overlap is believed to be very small, since Benedict's estimate for ornamental losses included only replacement costs, not any "aesthetic" value--the true value that would normally exceed the replacement value; and (2) soiling costs associated with household painting thay may have been partially estimated by Spence and Haynie (1972). Even so, the total value of these two areas of overlap would be quite small in proportion to the whole.

The fact is: we have little idea as to the extent the various effects are capitalized into property values rather than being capitalized into other assets or registered as losses in consumer surplus. Because of this lack of knowledge, it seems reasonable to consider the estimates of $5.9 billion and $7.0 additive, with minor adjustments.

If one considers the areas of overlap mentioned above, two adjustements must be made. First, $50 million for ornamental losses as determined by Benedict (1971) must be subtracted from the property value estimate. Second, $540 million for residential painting as determined by Spence and Haynie (1972) must be subtracted from the estimate of materials losses. By making these adjustments, the possibility of double-counting losses for plant ornamentals and soiling that are implicit in the property value estimator, is minimized. The adjusted gross damage estimate for 1970 then becomes $12.3 billion. This estimate can be allocated as follows: Aesthetics and Soiling, $5.8 billion; Health, $4.6 billion; Materials, $1.7 billion; and Vegetation, $0.2 billion.

SOURCE EMISSIONS

Using the general approach of Barrett and Waddell (1973), it may be instructive to relate the cost of pollution for each effect to the specific pollutants considered most responsible for that effect. EPA has estimated national emissions of principal pollutants by major source category for 1970. The principal pollutants are carbon monoxide (CO), particulates (part.), sulfur oxides (SO_x), hydrocarbons (HC), and nitrogen oxides (NO_x). National emissions of these pollutants were estimated to be 266 million tons in 1970 (see Table 20).

Approximately 54% of all national emissions come from transportation sources, including automobiles, trucks, buses, trains, aircraft, and other vessels. Fuel combustion in stationary sources such as public utility and industrial power plants, commercial and institutional boilers, and residential furnaces accounts for 17% of national emissions. Pollutants from industrial processes other than fuel combustion make up 14% of national emissions. Dumps and incinerators and related solid waste disposal practices generate some 4% of the

Table 20. ESTIMATES OF NATIONWIDE EMISSIONS, 1970*
(thousand tons/year)

Source Category	CO	Part.	SO_x	HC	NO_x	Total
Transportation	11.0	0.7	1.0	19.5	11.7	143.9
Fuel combustion in stationary sources	0.8	6.8	26.5	0.6	10.0	44.7
Industrial process losses	11.4	13.3	6.0	5.5	0.2	36.4
Solid waste disposal	7.2	1.4	0.1	2.0	0.4	11.1
Agricultural burning	13.8	2.4	Neg.	2.8	0.3	19.3
Miscellaneous	4.5	1.5	0.3	4.5	0.2	11.0
Total	148.7	26.1	33.9	34.9	22.8	266.4

* Source: J.H. Cavender, D.S. Kircher, and A.J. Hoffman, Nationwide Air Pollutant Emission Trends 1940-1970, Publ. No. AP-115, Environmental Protection Agency, Research Triangle Park, January 1973.

national emissions. The remaining 15% derives from a variety of sources including prescriptive burning of agricultural and forest fuels, wild forest fires, structural fires, coal refuse burning, organic solvent evaporation, and gasoline marketing.

ASSIGNMENT OF DAMAGE COSTS BY POLLUTANT AND SOURCE

The national air pollution-related health costs for mortality and morbidity in 1970 were estimated to be $4.6 billion. Most health studies reviewed in this paper, related health effects with particulates, sulfur dioxide, and sulfur oxide pollutants. These pollutants have been studied most commonly because: (a) there is generally more information on dose-response for these pollutants than for any others; (b) more and better air quality data is generally available for these pollutants than for any others; and (c) oftentimes, particulates measurements seem to be a fairly good index of overall air quality. Thus, until better information is forthcoming, it is assumed that the health costs of air pollution stem from particulates and sulfur oxides and from the sources of these two pollutants shown in Table 20. Costs will be allocated in this report according to the relative sensitivity coefficients for these pollutants as determined by Lave and Seskin. In other words, the relative importance of particulates can be determined as being accountable for 59% of the total costs and SO_x for the balance, or 41%.[147] Therefore, 59% or $2.7 billion of the $4.6 billion in health losses, is attributed to particulates and $1.9 billion, or 41% of the $4.6 billion, is estimated for the sulfur oxides-related health costs. Data deficiencies prohibit the estimation of the value of health effects associated with carbon monoxide, hydrocarbons, and oxides of nitrogen.

In the case of materials, pollution damages of $.7 billion to elastomers and dyes are attributed to oxidants and nitrogen oxides. The $.4 billion of damages to materials by sulfur oxides, estimated by Gillette, is identified as such. Because of the difficulty of separating the pollutant interactions, the remaining $.2 billion in the Spence-Haynie study (after adjusting for double-counting) will be equally divided in this attribution process between particulates and sulfur oxides. The remainder of the total materials cost estimate, $.4 billion from the Salmon study, is allocated in proportion to the emissions of pollutants, except for carbon monoxide, which, according to present knowledge, is not damaging to materials.[148] Give that hydrocarbons and nitrogen oxides react in the presence of sunlight to form photochemical pollutants (oxidants), emissions of these two pollutants will be combined to represent damage from oxidant pollution and from nitrogen oxides.

Results of the model developed by Benedict (1971) which predicts air pollution damage to vegetation, indicate that over 90% of the observable damage can be attributed to oxidants, with a smaller part for sulfur oxides, and with a still smaller fraction attributable to fluorides. This assignment will allocate the total estimate of air pollution damage to vegetation of $.2 billion to oxidants. There should be a small portion allocated to SO_x, but, because of its magnitude, it will not be displayed.

In considering the nature of the property value estimate, in that by assumption it measures aesthetic and soiling costs, it seems reasonable to assume that the total cost of $5.8 billion (adjusted for double-counting) can be allocated by evenly dividing the damage between particulates and sulfur oxides. Therefore, $2.9 billion in damage is associated with particulates and $2.9 billion with sulfur oxides.[149]

Results of assignment by effect and by pollutant are given in Table 21. In like manner, assignment of air pollution damages is made by effect and by source according to the relative contribution of damaging pollutants. This relationship is shown in Table 22.

Table 21. NATIONAL COSTS OF AIR POLLUTION DAMAGE, BY POLLUTANT AND EFFECT, 1970
($ billion)

Effect	SO_x			Particulate			O_x[a]			CO	Total		
	Low	High	Best	Low	High	Best	Low	High	Best	Best	Low	High	Best
Aesthetics & soiling[b,c]	1.7	4.1	2.9	1.7	4.1	2.9	?	?	?	*	3.4	8.2	5.8
Human health	0.7	3.1	1.9	0.9	4.5	2.7	?	?	?	?	1.6	7.6	4.6
Materials[c]	0.4	0.8	0.6	0.1	0.3	0.2	0.5	1.3	0.9	*	1.0	2.4	1.7
Vegetation	*	*	*	*	*	*	0.1	0.3	0.2	*	0.1	0.3	0.2
Animals	?	?	?	?	?	?	?	?	?	*	?	?	?
Natural environment	?	?	?	?	?	?	?	?	?	?	?	?	?
Total	2.8	8.0	5.4	2.7	8.9	5.8	0.6	1.6	1.1		6.1	18.5	12.3

Notes:

[a] Also measures losses attributable to NO_x.

[b] Property value estimator

[c] Adjusted to minimize double-counting

?Unknown

*Negligible

Table 22. NATIONAL COSTS OF POLLUTION DAMAGE, BY SOURCE AND EFFECT, 1970

($ billion)

Effects	Transportation	Stationary source fuel combustion	Industrial processes	Solid Waste	Agricultural burning	Misc.	Total
Aesthetics & soiling	0.2	3.1	2.0	0.1	0.2	0.2	5.8
Human health	0.1	2.2	1.7	0.2	0.2	0.2	4.6
Materials	0.6	0.8	0.3	*	*	*	1.7
Vegetation	0.2	*	*	*	*	*	0.2
Total	1.1	6.1	4.0	0.3	0.4	0.4	12.3

*Negligible

SECTION XIII
DISCUSSION

SOME LIMITATIONS OF GROSS DAMAGE ESTIMATES

There will be a temptation to use the \$12.3 billion estimate of the total cost of pollution as the measure of total benefits from pollution control. Yet, in fact, some of the pollution costs associated with the miscellaneous source category are not likely to become benefits resulting from general pollution reduction. This is because emissions from structural and wild forest fires are not normally controlled under traditional air quality management programs.

Also, there has been no comparative analysis of pollutants in terms of their relative severity. We do not know, for example, if a ton of SO_x causes a greater or lesser effect on vegetation than a ton of NO_x emissions. This aspect should temper any use of the damage estimates as allocated according to pollutant.

There will also be the temptation to use the pollutant cost estimates as indicative of relative seriousness. While they may be indicative of a general magnitude of seriousness, it is necessary to point out that few studies have attempted to assess oxidant-type pollution effects on human health and aesthetics. While no cost is shown for oxidant effects on human health, it would be naieve to assume that there are no such effects.[150] The problem is this: research has not yet progressed to that point where specific effects can be isolated and quantified. Because of this deficiency, the author has opted to conclude that instead of placing a zero cost in that particular cell, it would be more appropriate to indicate a lack of knowledge.

And there is another possibility: the results of some of these studies are spurious because sulfation or particulate measurements, for example, are acting as proxies for the presence of other environmental pollutants. This is a common problem in all non-laboratory studies. Research has shown that SO_x, NO_x, and HC all break down to the particulate state; thus, any individual particulate air quality measurement might also be representative of those pollutants that were originally emitted as gases. This possibility, then, complicates and raises serious questions of the validity of allocating costs by pollutant in the nice, neat way shown in Table 21. Also, these pollutants act synergistically to cause damage that perhaps would not occur when acting independently. So again, we have the problem of attaching weights to the different pollutants, which, by themselves are perhaps harmless, but which, in the presence of other pollutants, become harmful.

A problem of perhaps a different magnitude is whether or not damages will become benefits through the abatement of air pollution. In theory, the two should be the same. But, given the measurement problems that we either assume away or are somehow rationalized into nonsignificance, it is quite likely that damages estimated by some of the techniques discussed in Section III (especially the technical coefficients approach) are not "true" damages. This is so partly because of the obvious fact that the world is not optimal except for air pollution, consumers do not have sufficient knowledge about how they are being affected by air pollution, and because no allowance is made for substitution possibilities and adjustments that would be expected under a different set of environmental conditions. Thus, it is possible that the control of air pollution will result in benefits not heretofore yet measured.

Another inconsistency may occur in estimating gross damages because of some double-counting. Property value estimates, along with estimates of pollution effects on health, materials, and vegetation, are included in the total damage estimate of $12.3 billion. There may be some significant overlap of property value effects with the other categories. Information is not sufficient to determine the extent of double-counting.

In summary, the major limitations of gross damage estimates are: (a) estimates are often based on questionable air quality monitoring techniques or incomplete air quality data; (b) synergistic actions between pollutants complicates the categorization of effects and pollutant cost; (c) weak assumptions are often made in extrapolating experimental data to the effects on the true population; (d) since some of the extra-market effects are not amenable to quantitative assessment, they are lost in these estimates; (e) the confounding of effects prevents assignment of residual damages to specific pollutants or sources; and (f) there may be some double-counting between property value effects and other effects.

COMPARISONS AMONG GROSS DAMAGE ESTIMATES

The $12.3 billion estimate can be compared with those developed by others. Perhaps the earliest cited figure for the costs of pollution is $11 billion in 1959 or $60 per capita, which was extrapolated from results of the 1913 Mellon Institute Study on the basis of the commidity price index and population.[151] Ridker (1966) has suggested a total cost of pollution in 1970 as falling between $7.3 billion and $8.9 billion. Gerhardt (1969) estimated the cost of pollution to be $8.1 billion for 1968 within a range of $6.8 to $15.2 billion. The basic procedure of the latter two efforts involved five steps: (1) the identification of categories of air pollution damage; (2) an estimation of the total value of category regardless of the air pollution effects; (3) the assumption of an air pollution damage factor; (4) the application of this damage factor to the total value of the category; and (5) the summation of the estimates across all damage categories.

Recently, a $16.1 billion estimate for 1968 was generated by Barrett and Waddell (1973). It might be of value to mention how the Barrett-Waddell estimate of $16.1 billion for 1968 compares with the $12.3 billion estimate for 1970 developed in this paper. From a casual glance, one might assume that damages have been reduced by approximately $4 billion between 1968 and 1970. This is not necessarily true. It is hoped that a brief discussion will put the differences between the two estimates in better perspective.

There are several significant aspects that account for the differences between the two estimates. First, in the case of human health, the benefits of reducing pollution to the primary air quality standards for particulates and sulfur dioxide were estimated in this study, while Barrett and Waddell estimated the benefits of reducing pollution to zero. This would tend to result in a lower estimate for 1970.

Second, in the case of the property value estimator of aesthetic and soiling-related damages, there are two important things: (a) additional research showed that a marginal capitalized property value of $350 would be more accurate than the $200 value used in the earlier Barrett-Waddell study; and (b) levels of the air quality data for 1970 that were used were, in general, somewhat lower than those used for 1968. These tended to balance each other, thus resulting in no significant difference between the two property value estimates.

And third, in the case of materials damages, additional completed studies forced a lowering in this study of the economic losses associated with the corrosion of metals and those associated with painting. Also, a reevaluation of the available information suggested that there was no sound basis for estimating air pollution damages to certain materials such as cement and concrete, plastics, and wood; thus, estimates included for these damages in 1968 were dropped in this study. In addition to this fact, the lower SO_2 levels in 1970 resulted in a lower materials damage estimate for 1970. Implicit in all of these dollar values (as with that for vegetation losses), is the fact that inflation is another factor pushing air pollution damages higher in one year relative to the preceding one. The same can be said with respect to the increase in many instances of populations-at-risk. This would particularly be true in the area of health.

Thus, given that the bases for comparison of the two gross damage estimates are varied, it would be very difficult and probably not very meaningful to try to isolate what portion of the $3.8 billion difference could be attributed to the different assumptions made or different kinds of data used. Compared to the $16.1 billion estimate for 1968, the $12.3 billion estimated for 1970 in this paper is considered to be more refined and better specified--more refined in the sense that more logical and realistic assumptions are made and better specified in the sense that it is acknowledged that this is only the best estimate that falls within a specified range of $6.1 to $18.5 billion with some high degree of probability.

Most recently, Justice, et.al. (1973) have estimated that air pollution damages in 1970 ranged from \$2.0 billion to \$8.7 billion. While the range of damage estimates developed by Justice, et.al. overlap with the range developed in this report, there are significant differences between the two studies. The most significant difference pertains to health costs associated with air pollution, which Justice, et.al. estimate to range from \$62 million to \$311 million for 1970. This range is significantly lower than that reported in this report primarily because Justice, et.al. considered neither the additional work reported by Lave and Seskin after their Science article, nor the recent findings from EPA's CHESS program. Differences in other costs for specific effects rest largely on differences in the assumptions made, many of which that are suspect.[152]

The principal difference among all of the national damage estimates, including those reported in this study, is the determination of damage factors. The factors applied for national cost-of-pollution estimates for this study are believed to be determined by more reliable and objective procedures than in the previous studies.

SOME CONCLUDING REMARKS

It is the author's opinion that the estimate of \$12.3 billion is a reasoned, defensible one. Many pollution effects were not costed simply because of data limitations. The estimate generated through the use of property value method is believed to be, at a minimum, the lower bound on the "true" economic damages resulting from air pollution. To minimize double-counting, potential areas of overlap in ornamental losses and household painting were accounted for. By accounting for this overlap, the separate estimates determined by the technical coefficients approach--health, materials, and vegetation--were made additive to the estimate for aesthetics and soiling determined via the property value approach. While acknowledging that there is room for argument, it is believed that the available evidence suggests that the two estimates should be added together. While some may exercise the option of using \$7.0 billion as the gross damage estimate for 1970, it is argued here that \$12.3 billion is a sounder, more realistic estimate.

With respect to health, the estimates generated from Lave and Seskin (1973) and EPA can be considered a conservative measure of the real cost. It is argued that, in general, people are willing to pay more than the expenses of medical expenditures and lost productivity which they suffer, for air pollution abatement. While it is doubtful that the assumption of a straight-line functional relationship of mortality and morbidity and pollution is accurate, it is perhaps the most reasonable stance that can be taken at this time. In summary, these two studies provide a basis for taking a significant step in attempting to assess the economic effects of air pollution on human health. Again, little is known about the effects of automobile-and-related pollution on human morbidity and longevity.

The estimate of economic costs associated with materials degradation also appears to be a reasonable approximation. It is quite obvious from the numerous studies that only little dose-response information is available and in particular, little is known about air pollution effects on concrete and other building materials, paints, and some fibers. Also, little is known about adjustment costs that can be related to the use of more resistent materials because of air pollution.

Although vegetation losses due to air pollution are believed to be somewhat greater in magnitude than the suggested $.2 billion, little empirical evidence could support such an assumption. The figure is conservative because the yield and growth effects on plants are not generally considered in this estimate. There is much to learn about subtle, chronic, low-level-pollution yield effects. Also, no attempt has been made to quantify the effects of air pollution on the nutritional content of edible crops. Until some of these areas are investigated further, the vegetation loss estimate can only be used with an understanding of its many deficiencies.

There is still a lack of conclusive evidence on the soiling costs attributable to air pollution. Although Booz-Allen concluded that no significant economic impact of particulate pollution differentials existed with respect to residential cleaning and maintenance costs, the analysis in their study appears to be incomplete and warrants further work.

While the impact of air pollution on man's aesthetic values is believed to be considerable, because of data limitations, no direct estimates were generated. Quite obviously, man is bothered by poor visibility and noxious odors, but few attempts have been made to quantify these impacts. The lack of information suggests that only little is understood about the "psychic" costs people suffer as a result of a deteriorating air environment as well as the deleterious effects of air pollution on precious works of art.

As mentioned earlier, no known attempts have been made to investigate the economic effects of air pollution on animals, domestic or wild, even though pollutants such as chlorinated hydrocarbons, pose a threat to the balance of animal and related populations. It was also concluded that economic analysis of any long-run implications of perturbations to our ecosystem might be premature.

Obviously, of the different methods that might be used to estimate pollution costs, the technical coefficients approach has been the most popular. Why? Because of its simplicity in handling and translating from physical or biological damage to economic loss. Market studies, or more specifically, the property value approach, with its sophisticated econometric handling of data, has provided the soundest basis for estimating pollution costs. Even though the assumption is often made that most aesthetic-related costs are implicitly measured in this approach, some uncertainty exists as to what effects are actually measured.

It is likely that some combination of the different methods surveyed will ensure the most accurate assessment of the economic damages resulting from air pollution insults. The technical coefficients approach should prove valuable in understanding the basic cause-effect relationships affecting adjustments in the market place. The property value approach should be applied to rural areas and should be tested with other pollutant measurements. The public polling technique will be used in understanding the social, aesthetic, and psychological or "psychic" effects of adjustments that people experience. Different problems will require different handling.

In any attempt to determine a dose-response relationship, the large number of variables that must be considered presents a serious problem in the isolation of those parameters that are significant. Yet of course, excluded variables introduce a bias only to the extent they are not orthogonal to the included variables. Also, the application of different discount rates in the determination of total costs of pollution could change the relative cost estimates. The ten percent rate of interest used in the residential property value to estimate results is an understatement of costs relative to health costs which applied an eight percent interest rate.

RECOMMENDATIONS

Gross damage estimates are only the first step in providing information on the benefits of pollution abatement to policy-makers. Such estimates do point to the seriousness of air pollution problems. However, the U.S. Government and most individuals in the U.S. are already convinced that air pollution is indeed a serious problem.

Expansion and refinements in pollution effects studies should be undertaken. Such information on dose-response--damage functions--would provide a sounder basis for estimating benefits of abatement. However, the information which is generated should be over a range of realistic ambient air quality or control levels. Damage functions should be constructed on a pollutant-by-pollutant basis or group basis when pollutants act, or can be acted upon, together, and, most importantly, should be analyzed in a regional cost-benefit, policy-making framework (see the example described in Section III).

Research should also be expanded in the area of the different methods that can be utilized in the assessment of the social cost of air pollution. It is likely that some combination of the different methods surveyed in this paper will ensure that most accurate assessment of the economic damages resulting from air pollution insults. Also, attempts should be made to understand and identify the economic and social significance of adjustments people make because of deteriorating environmental quality.

SECTION XIV

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3. Under most circumstances, proportionate reduction requires a different mix of source-specific pollution control than does marginally allocated reduction. Therefore, regional pollution control benefits, both in magnitude and distribution, are likely to differ under the two enforcement schemes. Here, this complication is ignored in order to keep the analysis relatively simple; it should, of course, be taken into account in any real-world analysis.

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expenditures identified in Table 1 in Rice (p. 3) plus the total mortality and morbidity costs identified in Table 32 (p. 110), also from Rice.

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